
sundance
CHIWETEL EJIOFOR
MAXWELL SIMBA
A NETFLIX FILM
THE BOY WHO HARNESSED THE WIND
BASED ON THE INCREDIBLE TRUE STORY
NETFLIX | MARCH 1

JOURNEYS IN FILM™
educating for global understanding

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About *Journeys in Film*

Founded in 2003, ***Journeys in Film*** operates on the belief that teaching with film has the power to prepare students to live and work more successfully in the 21st century as informed and globally competent citizens. Its core mission is to advance global understanding among youth through the combination of age-appropriate films from around the world, interdisciplinary classroom materials coordinated with the films, and teachers' professional-development offerings. This comprehensive curriculum model promotes widespread use of film as a window to the world to help students to mitigate existing attitudes of cultural bias, cultivate empathy, develop a richer understanding of global issues, and prepare for effective participation in an increasingly interdependent world. Our standards-based lesson plans support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

Selected films act as springboards for lesson plans in subjects ranging from math, science, language arts, and social studies to other topics that have become critical for students, including environmental sustainability, poverty and hunger, global health, diversity, and immigration. Prominent educators on our team consult with filmmakers and cultural specialists in the development of curriculum guides, each one dedicated to an in-depth exploration of the culture and issues depicted in a specific film. The guides merge effectively into teachers' existing lesson plans and mandated curricular requirements, providing teachers with an innovative way to fulfill their school districts' standards-based goals.

Why use this program?

To be prepared to participate in tomorrow's global arena, students need to gain an understanding of the world beyond their own borders. ***Journeys in Film*** offers innovative and engaging tools to explore other cultures and social issues, beyond the often negative images seen in print, television, and film.

For today's media-centric youth, film is an appropriate and effective teaching tool. ***Journeys in Film*** has carefully selected quality films that tell the stories of young people living in locations that may otherwise never be experienced by your students. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven,* play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home,* watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider,* tour an African school with a Nobel Prize–winning teenager in *He Named Me Malala,* or experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble.*

In addition to our ongoing development of teaching guides for culturally sensitive foreign films, ***Journeys in Film*** brings outstanding documentary films to the classroom. We have identified exceptional narrative and documentary films that teach about a broad range of social issues in real-life settings such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. ***Journeys in Film*** guides help teachers integrate these films into their classrooms, examining complex issues, encouraging students to be active rather than passive viewers, and maximizing the power of film to enhance critical thinking skills and to meet the Common Core Standards.

Journeys in Film is a 501(c)(3) nonprofit organization.

A Letter from Chiwetel Ejiofor

I hope you enjoyed watching the film *The Boy Who Harnessed the Wind.*

William's story embodies the creativity of young people and acts as a powerful reminder of the achievements we can make when we are not afraid of failure. He encountered many obstacles, but his determination to get an education and unstoppable drive to do what he believed in will act, I hope, as an inspiration to you in this course.

This film tells the true story of a family in Malawi and the difficulties they faced; external factors like the weather, environment, politics, religion, and education have a profound effect on the daily life of many Malawians. I hope this film and the course spark a much wider discussion and action to engage with some of the issues that the film touches on.

William's story continues to inspire the next generation of innovators in Africa and around the world. I hope that watching *The Boy Who Harnessed the Wind* and the curriculum help to inspire you to never give up on your dreams.

Yours sincerely,

The Environmental Crisis

Enduring Understandings

- Natural systems are interdependent.
- Humans depend on Earth's resources.
- The actions of humans impact the health of the environment.
- Climate change influences regional geography.
- Climate change impacts human communities.
- Climate-related environmental problems change over time.
- Risks to environmental and human health can be managed and reduced.
- A healthy, equitable, and sustainable future for human communities on Earth is possible.

Essential Questions

- What is "geography"?
- How do the climate-related movements of water affect the geography of a region?
- Why is it important to learn about climate change?
- How does the geography of a region impact the human communities of that region?
- How do the human communities of a region impact its geography?
- What is "desertification"?
- How is desertification related to climate change?
- What evidence of climate change is unique to sub-Saharan Africa?
- How does flood and drought cycling from climate change impact human communities in Africa?
- How does climate change affect the health and standard of living in African communities?
- Who is responsible for climate-related environmental justice in human communities?
- How can scientific research be used to study climate change?
- What types of scientific data are currently used to characterize climate change?
- How do scientists use data to make long-term climate forecasts?
- How will the earth's climate patterns continue to change in the future?

Notes to the Teacher

For most American students, the East African terrain between Egypt and South Africa is a mystery. In this lesson students learn about the geography of the landlocked sub-Saharan country of Malawi and its sub-tropical climate with rainy and dry seasons. The alternation of droughts and floods, which creates food shortages despite the government's promise of access to nutritionally adequate food, means that approximately two-thirds of the people experience hunger during the year. While using Malawi as a case study, the lesson also points to the additional threat of drought in much of Africa due to climate change. Prior to the lesson students should view *The Boy Who Harnessed the Wind*; alternatively, if you are using the lesson to introduce the film, show a selection of clips from the film that focus on climate.

The activities in this lesson have been designed for use as individual modules or tiered instruction with each new lesson component building upon the last. A review of the activities prior to delivery is highly suggested to best determine the class time needed for each one and appropriately plan for materials acquisition. While the suggested lesson duration is between three and five one-hour periods, the activities can easily be modified based on time available or the place in the course curriculum where the lesson can best be integrated. The components for this lesson collectively explore the relationship between human communities and shifting climate trends in Africa and elsewhere on our planet.

This lesson assumes students have some background on the fundamentals of weather and climate, the water cycle, and climate change. The following videos are great resources in the event review material is needed:

Weather and Climate:
https://www.youtube.com/watch?v=cBdxDFpDp_k

Water Cycle:
https://pmm.nasa.gov/education/videos/tour-water-cycle

Climate Change:
https://www.climaterealityproject.org/climate-101

Please note that all suggested video links in this lesson can be projected for students as a group or shared with students for use on individual devices, depending on the classroom technology available. Students should also be familiar with introductory coordinate-system (x-/y-axis) graphing/graph analysis.

Part l of this lesson investigates the complex role of human communities as part of the geography of the sub-Saharan region, casting a unique spotlight on the climate-related factors which can influence this positioning. A full set of copies of **Handout 1: Malawi: Sensing Place** and **Handout 2: 30-Minute Ph.D.** should be made for each class. It should be noted that devices with Internet access are needed for this portion of the lesson. In addition, the research component of **Handout 2: 30-Minute Ph.D.** can be completed in class or assigned as homework ahead of Part 2 of the lesson.

In Part 2 of this lesson, students explore the influence of flood and drought cycling from shifting climate trends on the human experience in the communities of Malawi. They begin thinking about the unique impact of climate-related changes on human health and standards of living through the lens

of equity across the African continent. Copies of **Handout 3: A Day in the Life** and **Handout 4: No Two Countries the Same** should be made for each class for this part of the lesson. It should also be noted that the images from **Handout 3: A Day in the Life** can either be printed and distributed to individual groups or simply shared with the class depending on the classroom technology available.

Furthermore, the activity components which accompany **Handout 3** and **Handout 4** can be completed in class or assigned as homework depending on the amount of time available. It is also important to note that Internet access is needed for use on **Handout 4.**

Part 3 introduces students to the concept of scientific modeling as well as the data reporting involved in climate forecasting in Africa and worldwide. This portion of the lesson requires a class set of **Handout 5: And the Data Suggest?** and individual device access to the Internet. Please note that the duration of this activity can vary as a function of class and/or curriculum time available.

Common Core Standards Addressed by this Lesson

History/Social Studies

CCSS.ELA-LITERACY.RH.9-10.1
Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

CCSS.ELA-LITERACY.RH.9-10.2
Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.

CCSS.ELA-LITERACY.RH.9-10.3
Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

CCSS.ELA-LITERACY.RH.9-10.4
Determine the meaning of words and phrases as they are used in a text, including vocabulary describing political, social, or economic aspects of history/social science.

CCSS.ELA-LITERACY.RH.9-10.5
Analyze how a text uses structure to emphasize key points or advance an explanation or analysis.

CCSS.ELA-LITERACY.RH.9-10.7
Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

CCSS.ELA-LITERACY.RH.9-10.9
Compare and contrast treatments of the same topic in several primary and secondary sources.

Science and Technical Subjects

CCSS.ELA-LITERACY.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-LITERACY.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

CCSS.ELA-LITERACY.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Writing

CCSS.ELA-LITERACY.WHST.9-10.6
Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.

CCSS.ELA-LITERACY.WHST.9-10.7
Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

CCSS.ELA-LITERACY.WHST.9-10.8
Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

CCSS.ELA-LITERACY.WHST.9-10.9
Draw evidence from informational texts to support analysis, reflection, and research.

Duration of Lesson

Three to five one-hour periods

Assessments

Completion of the *Malawi: Sensing Place* map analysis

Completion of the *30-Minute Ph.D.* research activity

Completion of the *A Day in the Life* visual analysis activity

Completion of the *No Two Countries the Same* analysis activity

Completion of the *And the Data Suggest?* data analysis activity

Group discussion

Student presentations

Materials

Writing utensils

Blank index cards

Blank paper

White board

White board markers

Presentation Devices with Internet access

Individual devices with Internet access (if available)

Colored pencils

Markers

Handout 1: Malawi: Sensing Place Handout 2: 30-Minute Ph.D.

Handout 3: A Day in the Life

Handout 4: No Two Countries the Same Handout 5: And the Data Suggest?

Access to Bill Nye video at https://www. climaterealityproject.org/climate-101

Procedure

Part 1: Malawi: Portrait of a Place

1. Begin by distributing the index cards and writing utensils to the class (one index card per student). Ask the students to write (1) the word "geography" on one side of the index card and (2) their best definition of the term on the same side. Allow the students to work independently.

2. When a few minutes have passed, ask the students to exchange their index cards with a partner. Invite a few students to share the definition on the card they received. Then read aloud a definition of the term from the Oxford English Dictionary; it can be found at https://www.lexico.com/en/definition/geography.

3. Host a brief discussion with the class using the following questions as prompts.

   - How does the definition of "geography" on your index card compare with the official one from the Oxford English Dictionary? Please explain.
   - What elements of the formal definition of "geography" are missing from the one on your index card? (An example here might be the relationship between human activity and Earth's features).
   - How would you describe the geography of your own region?
   - Consider the film *The Boy Who Harnessed the Wind*. How would you describe the geography of Malawi? What evidence do you remember from the film?

4. On the board, draw two columns titled "Similar" and "Different." Ask the students to think about the similarities and differences between the geography in their own region and in Malawi. Invite students to come to the board and add their thoughts to each column. Ask the students what they think is the biggest difference in geography between their region and Malawi. Host a brief discussion using the students' responses as a framework for the conversation.

5. Tell the students they will have the opportunity to learn a little more about the geography of Malawi. Divide the class into groups of 2–3 students. Distribute copies of **Handout 1: Malawi: Sensing Place** to each group. Read the instructions out loud and allow approximately 20 minutes (more or less, as time permits) for students to complete the handout. NOTE: For this activity, students should have access to the Internet and/or other print resources such as journals or newspapers. When groups are finished, review their responses to each prompt in the form of a short discussion.

   Suggested responses for **Handout 1**:

   a. Answers to the first part of this question will vary depending on where this lesson is taught. Malawi is a landlocked country located in southeastern Africa.

B.

C. The southern border of the Sahara Desert does not appear on this map. Malawi is approximately 4000 km from the Sahara Desert.

D. Sub-Saharan countries are African countries which are located to the south of the Sahara Desert. Sub-Saharan countries have climate and weather trends which are related, but not the same as Saharan countries.

E. The climate of Malawi is semi-arid (dry) due to its location just south of the equator. Weather patterns in the country demonstrate strong seasonal variability, however. A hot and humid rainy season ranges from November to April. The country is dry and cool the remainder of the year.

F. Answers to this question may vary. According to the United Nations, Malawi is experiencing one of the highest rates of desertification in the world. The number of people who inhabit degraded land increases dramatically on a yearly basis. These trends are the strongest in rural communities, where non-sustainable agricultural practices, high rates of deforestation, and soil erosion from highly-variable climate patterns are most prevalent.

G. Answers to this question may vary, but should include heavy seasonal rain, increased seasonal flooding, extremely dry conditions, increased soil erosion from heavy rains, extended drought conditions, poor crop production, reduced vegetation, reduced water availability.

6. Ask the students to consider the shifts in climate they discussed in their answers to Question 7 from **HANDOUT 1: MALAWI: SENSING PLACE**. Ask them to think about the impacts these changes might have on human communities

in Malawi. Invite several students to share their thoughts with the class and host a brief discussion. The following questions may be helpful to guide the conversation.

- How might shifts in climate impact human communities in Malawi?
- What do you think people in this region need the most in terms of their challenges with climate-related lifestyle shifts?
- What groups of people do you think are affected most by climate-related changes in this region?

7. Explain to the students they will have the chance to examine the geography of Malawi in a bit more depth through the lens of human communities. Divide the class into small groups. Distribute a copy of **Handout 2: 30-Minute Ph.D.** to each student and assign each group a number from 1 to 5. The group numbers correspond to the numbered prompts on the handout. Read the instructions out loud and allow students time to complete the assignment. Student presentations at the end of this activity should be informal and no longer than 3–4 minutes. NOTE: This activity can be completed using 30–45 minutes of in-class time or can be assigned as homework for the next class; access to the Internet is necessary. If your students have difficulty finding articles or you wish to save time, here are a few articles you can suggest to them:

Prompt 1

Why climate scientists predict even bigger hurricanes are coming to our coasts

https://qz.com/africa/1580662/cyclone-idai-shows-more-devastating-hurricanes-coming-to-coasts/

UNICEF Malawi humanitarian situation report—flood situation report: No. 4 (5 April 2019)

https://reliefweb.int/report/malawi/unicef-malawi-humanitarian-situation-report-flood-situation-report-no4-5-april-2019

Prompt 2

Malawian women struggle for land rights despite equality drive

https://www.reuters.com/article/us-malawi-landrights-women/malawian-women-struggle-for-land-rights-despite-equality-drive-idUSKCN1M51GQ

Prompt 3

Why Cyclone Idai was so destructive

https://www.nationalgeographic.com/environment/2019/03/why-mozambique-cyclone-idai-was-so-destructive/

Warning: Climate change can harm your health

https://www.sciencenewsforstudents.org/article/warning-climate-change-can-harm-your-health

While the rich world braces for future climate change, the poor world is already being devastated by it

https://www.cnn.com/2019/03/31/africa/poorest-hit-the-hardest-climate-change-mozambique-intl/index.html

Prompt 4

Malawi forests shrink as power deficit fuels charcoal business

https://www.reuters.com/article/us-malawi-forests-climate/malawi-forests-shrink-as-power-deficit-fuels-charcoal-business-idUSKBN0OA12P20150525

Malawi: Government reaffirms commitment towards environmental conservation
https://allafrica.com/stories/201906250098.html

Malawi turns to coal to address its energy crisis
http://www.earthisland.org/journal/index.php/articles/entry/malawi-turns-to-coal-energy-crisis/

Prompt 5

Mining in Malawi brings forced evictions and ruined crops, report says
https://www.theguardian.com/global-development/2016/sep/27/mining-malawi-brings-forced-evictions-ruined-crops-human-rights-watch-report-says

Early action to protect and enhance the livelihoods of drought-affected smallholder farmers in Malawi against the lingering 2018/2019 El Nino event
https://reliefweb.int/report/malawi/early-action-protect-and-enhance-livelihoods-drought-affected-smallholder-farmers

Part 2: Does Geography Matter?

1. After having watched all or part of the film *The Boy Who Harnessed the Wind*, begin this part of the lesson by asking the students to reflect on ways in which climate change has impacted the lives of the people living in Malawi. Invite several students to share their thoughts, hosting a brief discussion based on the responses.

2. Next, distribute one piece of blank paper (lined paper also works) to each student in the class. Write the following four prompts on the board, asking the students to record the prompts at the top of the paper.
   - Describe what is happening in this photo.
   - What aspects of this photo tell you about the geography of Malawi? List as many as possible.
   - How does this photo show the impact of alternating flood and drought cycling on the people of Malawi?
   - How does this photo make you feel? Be specific.

3. Divide the class into 6 groups, explaining to the students that they will be looking at images related to Malawi's alternating flood and drought cycles. Distribute the images from **Handout 3: A Day in the Life**; each group should begin with a different image.

4. Tell the groups they will have time to examine and discuss each image. They should respond to the four prompts on the board for each image. Allow 3–5 minutes for students to respond to their first image. If time permits, invite the groups to exchange images and conduct a second round of analysis. [NOTE: Work on this activity can vary from one to all six images, depending on the time available. If time is limited, one or more of the images can be assigned as homework.]

5. When students have finished their analysis, collect the photos. Invite each group to share their responses to the prompts. Host a discussion based on students' responses, placing emphasis on the feelings students have about the images they assessed. Each image discussed should be held so it can be seen by everyone during the discussion. Alternatively, the images can be shown on a projector.

6. Next, ask the students the following questions, inviting several to share their thoughts with the class.

- Do you think the scenes of droughts and floods in Malawi from the film *The Boy Who Harnessed the Wind* are similar to the images you viewed with your group? Please explain.
- What elements of the images you viewed ate different from where you live?
- A large percentage of people in Malawi experience hunger due to food shortages from droughts and floods each year. Is this a problem where you live? Please explain.
- Do you think it is fair for the people of Malawi to suffer food shortages as the result of an environmental dilemma at least partially created by humans (such as climate change)? Please explain.
- How do you think food access for the people of Malawi will continue to change as the result of shifting climate trends on Earth?

7. Ask the students what percentage of the population in Malawi they think experienced poverty as the result of conditions related to climate. (According to the International Monetary Fund[1], in 2010, 50% of people in Malawi lived below the international poverty standard of $1.90 per day; 25% were in extreme poverty, unable to satisfy food needs. Poverty was worse in rural areas.) Ask students how they think this aspect of Malawi compares to other countries in the world. Call on several students to share their thoughts.

8. Explain to the students that the next activity invites them to examine a system designed by the United Nations to evaluate the health and standard of living of different countries; it is called the Human Development Index (HDI). Tell them this system is used worldwide and assesses key dimensions of human development using such metrics as healthy lifestyle and standard of living. Tell the students they will explore aspects of the HDI resulting from poor environmental conditions related to climate change (such as food shortage) in both Malawi and their country of origin.

9. Divide the students into groups of 2–3 and distribute copies of **Handout 4: No Two Countries the Same.** Read the instructions out loud and be sure students understand the meaning of each term on the list. Some are obvious; for other topics such as gender, it would be helpful to show students how to click on the "+" to view the factors that have been evaluated. Allow groups 20–30 minutes to complete the data table and thought questions. Explain that the students will need to click the (+) to expand the list of category subheadings for each Human Development Indicator as part of their research for Question 3. [NOTE: While this activity is designed for in-class completion, a part or all of it could easily be assigned as homework for the next class.]

10. When groups are finished, review the student responses to each prompt in the form of a short discussion.

11. As an optional assignment for the next class, invite students to refresh their understanding of climate change as presented by Bill Nye in this short video: https://www.climaterealityproject.org/climate-101

1 https://www.imf.org/~/media/Files/Publications/CR/2017/cr17184.ashx

Part 3: The Bigger Picture

1. Begin by distributing a blank sheet of paper and colored pencils to each student in the class. Ask the students what images come to mind when they think about climate change. Give the students 10-20 minutes to create a "sketch" of climate change as a warm-up challenge; they should work quietly and independently.

2. Invite several students to share their sketches with the rest of the class. Host a brief discussion about climate change using the following questions as a framework for the conversation.

   - On a scale from 1 to 10, how familiar are you with climate change? (1 = What is climate change?/10 = Superstar expert climate change specialist) Please explain.
   - How does climate change impact your life?
   - How does the story of climate-related floods and drought in Malawi relate to the rest of the African continent?
   - What do you think might be the best way of teaching and inspiring people to want to do something about climate change?
   - How do we know that the Earth's climate will continue to change in the future?

3. Explain to the students that they will use an online tool called the Climate Reanalyzer to examine sets of past and current data collected about shifting climate trends in Africa. They will use the site, produced by the Climate Change Institute at the University of Maine, to visualize long-term predictions for how climate will continue to change in this part of the world.

4. Divide the students into groups of 2–3. Distribute copies of **Handout 5: And the Data Suggest?** to each group. Read the instructions out loud; allow groups approximately 30 minutes to complete the data table and thought questions. [NOTE: The students will need Internet access for this activity. Students who finish early should be encouraged to explore other pages of the website.]

5. When groups are finished, review their responses to each prompt in the form of a short discussion. Then, ask the students these final questions. NOTE: Student responses to these prompts may offer an elegant segue into one or more of the proposed extension activities that follow, many of which highlight climate advocacy as a main theme.

   - Based on your work using the Climate Reanalyzer, how concerned should we be for the well-being of African countries if climate change becomes worse over time? Please explain.
   - What are some ideas you have to help bring awareness and inspire positive change in African communities that, like those in Malawi, are affected by flooding, drought, and famine due to climate change?

6. If time permits, students can experiment with changing the "Variable" option in the drop-down menu box provided as a way of thinking about shifting temperatures and other climate-related factors which may continue to impact African communities in the future. Suggested variables to explore include precipitation, wind speed, and cloud cover. The students can also compare these changes in Africa and those in other world locations by manipulating the "Region" menu.

Extension Activities

1. Assign students into groups where each student will play the role of a community member in Malawi. Conduct a mock town-hall meeting and have members of each group address the following question through the lens of the role: *What can be done to prevent food shortages due to heavy flood and drought cycling in this village?* Roles might include government officials, teachers, health care workers, local business owners, tourists, and/or visiting scientists.

2. To inspire students to begin thinking about their own water use as they study the cycles of flooding and drought in Africa, ask them to calculate their own water footprint using this online water usage calculator: https://www.watercalculator.org/. This activity could serve as a preliminary component to the lesson as a warm-up prompt or could be assigned ahead of any of the individual lesson sections as homework.

3. Invite students to write a letter to a newspaper or government official to share their concerns about and demand actions on the impact of climate change on African countries such as Malawi.

4. Have students write and produce a podcast about climate change and famine in Africa. The following links may be a helpful place to start: **Starting Your Podcast: A Guide for Students** (https://www.npr.org/2018/11/15/662070097/starting-your-podcast-a-guide-for-students), **Project Audio: Teaching Students How to Product Their Own Podcasts** (*New York Times*) (https://www.nytimes.com/2018/04/19/learning/lesson-plans/project-audio-teaching-students-how-to-produce-their-own-podcasts.html).

Additional Resources

William Kamkwamba's 2007 TEDx Talk
https://www.ted.com/talks/william_kamkwamba_on_building_a_windmill?language=en

Water Footprint Calculator
https://www.watercalculator.org/

Weather Versus Climate Change
https://www.youtube.com/watch?v=cBdxDFpDp_k

A Tour of the Water Cycle
https://pmm.nasa.gov/education/videos/tour-water-cycle

Climate 101 with Bill Nye
https://www.climaterealityproject.org/climate-101

350.org
https://350.org/about/

350.org Africa
https://350africa.org/

Climate Reanalyzer
https://climatereanalyzer.org/

United Nations Human Development Reports
http://hdr.undp.org/en

United Nations Environment Programme: Africa
https://www.unenvironment.org/regions/africa

United Nations Africa Renewal Programme
https://www.un.org/africarenewal/

Africa feeling the heat of climate change
https://www.un.org/africarenewal/magazine/may-july-2017/africa-feeling-heat-climate-change

Beyond Carbon
https://www.beyondcarbon.org/?utm_medium=ads-dcm&utm_source=google&utm_campaign=BeyondCarbon&utm_content=climatechange_BeyondCarbon

Global heating to inflict more droughts on Africa as well as floods
https://www.theguardian.com/science/2019/jun/14/africa-global-heating-more-droughts-and-flooding-threat

Hike in record-dry months for Africa's Sahel worries scientists
https://www.reuters.com/article/us-climatechange-africa-drought/hike-in-record-dry-months-for-africas-sahel-worries-scientists-idUSKBN1OC1PT

Climate change is creating a new atmosphere of gender inequality for women in Malawi
https://www.teenvogue.com/story/climate-change-gender-inequality-women-malawi

Planet is entering a 'new climate regime' with 'extraordinary' heat waves intensified by global warming, study says
https://www.washingtonpost.com/weather/2019/06/11/climate-change-intensified-last-summers-northern-hemisphere-heat-wave-it-may-be-starting-all-over-again/?utm_term=. f4c8176973be

Handout 1

Malawi: Sensing Place

Instructions: Use the map provided to answer the questions below on a separate sheet of paper. NOTE: You may use the Internet or other resources for research where needed.

[Source: https://commons.wikimedia.org/wiki/File:LocationMalawi.svg]

1. The country of Malawi is shaded red on the map. How would you describe the location of Malawi in relationship to your own country? To the rest of Africa?
2. Label Malawi on the map. Then, research the names of all countries which share a border with Malawi. Label these countries on the map.
3. Research the location of the Sahara Desert in Africa. Does the southern border of the Sahara Desert appear on this map? Using online resources, can you determine approximately how far Malawi is from the Sahara Desert?
4. Malawi is considered a sub-Saharan country. What does this mean? Why might Malawi become a Saharan country at some point?
5. Malawi has a sub-tropical climate. Using your understanding of climate, what kind of weather and climate patterns might exist in sub-Saharan countries like Malawi that allow them to be considered "sub-tropical"? Please explain.
6. The United Nations describes desertification as *land degradation in typically dry areas resulting from various factors, including climatic variations and human activities*. Based on this definition, do you think Malawi is experiencing desertification? Please explain.
7. What evidence from the film *The Boy Who Harnessed the Wind* demonstrates shifts in climate related to desertification in Malawi?

Handout 2

30-Minute Ph.D.

Instructions: Each of the prompts below relates to some aspect of the definition of geography with respect to human communities. For this assignment, you will become a Ph.D.-level expert on a unique, human-based feature of the geography of Malawi in a short period of time. Circle or highlight the prompt below to which your group has been assigned. Then, using the Internet, find an article which deals with your assigned topic. Read and summarize the article with your group, making sure you record (1) the title of the article and (2) the website/publication from which it came. Your group should be prepared to give a brief presentation (your dissertation!) to the class summarizing the article and explaining how it relates to your assigned prompt.

Prompt 1	How does the land in Malawi influence where the country's people live?
Prompt 2	Who owns the land in Malawi?
Prompt 3	How does the land in Malawi influence human communities in the region?
Prompt 4	How do human communities impact the land of Malawi?
Prompt 5	How do human communities in Malawi rely on the land in the surrounding region?

Handout 3 ▸P.1

A Day in the Life

Instructions to teacher: Print, cut out, and distribute the photos below (one photo per student group; group size will vary depending on class size). Then, follow the instructions in Part 2 of the Procedure above, beginning with Step 3.

Photo 1

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:ILRI,_Stevie_Mann_-_Household_takes_refuge_from_the_rain_in_central_Malawi.jpg

Handout 3 ▸P.2 A Day in the Life

Photo 2

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:Africa_Food_Security_15_(10665294293).jpg

Handout 3 ▸P.3

A Day in the Life

Photo 3

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:Hauling_water_in_Malawi.jpg

Handout 3 ▸ P.4 A Day in the Life

Photo 4

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:Displaced_people_in_Bangula_evacuation_camp.jpg

Handout 3 ▸P.5

A Day in the Life

Photo 5

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:Harvesting_in_Chikhwawa_Malawi.jpg

Handout 3 ▸P.6 A Day in the Life

Photo 6

Source: wikimedia.org
https://commons.wikimedia.org/wiki/File:Malawi_AIDS_Orphans.jpeg

Handout 4 ▸P.1

No Two Countries the Same

Instructions: The United Nations asserts that "people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone." The Human Development Index (HDI) designed by the United Nations assesses key dimensions of human development, among which are a long and healthy life and decent standard of living. In this activity, you will explore aspects of the HDI resulting from poor environmental conditions related to climate change. Your mission is to examine the difference in HDI between Malawi and the country where you live.

To begin, visit the United Nations Development Report website at http://hdr.undp.org/en. Click the menu at the top and choose "Country Profiles." Choose "Malawi" and record the listed values for each Human Development Indicator in the appropriate column. Then, repeat the process for "Your Country" (be sure to list the name). When you are finished, please answer the thought questions on the next page.

	Country	
Human Development Indicators	**Malawi**	**Your Country:**
Health		
Education		
Income/Composition		
Inequality		
Gender		
Poverty		
Work, Employment, and Vulnerability		
Human Security		
Trade and Financial Flows		
Mobility and Communication		
Environmental Sustainability		
Demography		
Socio-Economic Sustainability		
Human Development Index (HDI)		
Country Rank		

Handout 4 ▸ P. 2

No Two Countries the Same

Thought Questions

1. In your own words, describe the Human Development Index (HDI). How is it used?

2. Why do you think the HDI is so low in Malawi? What evidence of this did you see in the film *The Boy Who Harnessed the Wind*?

3. Consider aspects of the HDI in Malawi that might be the result of poor environmental conditions related to a changing climate. Using the website provided in the instructions, research three Human Development Indicators with category subheadings that may be direct or indirect consequences of climate change. *Record your findings in the table below.*

Human Development Indicator	Subheading	Relationship to Climate Change
(Example) Health	*(Example)* Child malnutrition	*(Example)* Child malnutrition may be the result of food shortages related to severe drought conditions from increasing temperatures in Malawi.

Handout 4 ▸ P. 3

No Two Countries the Same

4. How does the HDI of Malawi compare to your country? Be as specific as possible.

5. How does it make you feel to learn that countries like Malawi have such a low HDI?

6. Who should be responsible for addressing low standards of living related to climate-related changes in environmental conditions (such as drought-related food shortages)? Be specific.

Handout 5 ▸P.1

And the Data Suggest?

Instructions: One of the most challenging aspects of climate science relates to the difficulty in predicting the long-term trends and impacts of a shifting climate. One of the best tools available to the scientific community is the practice of scientific modeling, the process of using historical data to best inform forecasts for future trends. In this activity, you will use an online tool called the *Climate Reanalyzer* to examine data sets related to temperature in Africa and other parts of the world. You will then use the results of your analysis to make informed predictions about future temperature trends in these locations.

To begin, visit the Climate Reanalyzer website at https://climatereanalyzer.org. On the menu to the left of the large image of Earth, click "Monthly Reanalysis Timeseries." Then, use the data and images provided to answer the thought questions below to the best of your ability.

1. On the "Monthly Reanalysis Timeseries" page, set the following graph parameters using the drop-down menus provided:

Dataset	Reanalysis [3rd Gen] – ERA-Interim (1979-2015)
Variable	Mean Temperature 2m
Level	1000 mb (this should be a set value)
Month	Annual
Region	Africa

2. Click the "Plot" button. Use the "Annual Temperature at 2 meters" graph that is generated to answer the questions below:

A. What do the x- and y-axes on this graph represent?

B. How would you describe the relationship between temperature and time in Africa as demonstrated by this graph?

C. What is the highest temperature shown on this graph? What year was this temperature recorded?

D. What range of time (in years) does this data set cover?

Handout 5 ▸P.2

And the Data Suggest?

3. Consider ways in which annual temperatures in Africa could continue to change over the next fifty years.

A. On the graph below, plot what you think the annual temperature trend in Africa will look like for a period of fifty years from today. Be sure to appropriately scale and label your x- and y-axes.

B. Please describe the graph you created above. What factors do you think will contribute to your forecasted temperature trends in Africa?

4. According to the National Aeronautics and Space Administration (NASA), the Intergovernmental Panel on Climate Change (IPCC) asserts the following:

> *"…increases in global mean temperature of less than 1 to 3 degrees Celsius above 1990 levels will produce beneficial impacts in some regions and harmful ones in others. Net annual costs will increase over time as global temperatures increase. Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time."*[1]

If you lived in Africa, would you be concerned about the predicted annual temperature trends moving into the future? Please explain, using the data you analyzed here to support your assertions.

[1] https://climate.nasa.gov/effects/

Wind Power: History and Engineering

Enduring Understandings

- Wind is formed by the uneven heating of the Earth's surface by solar radiation, differences in topography, and the rotation of the Earth.
- Gases move from areas of high pressure to low pressure.
- Local and atmospheric winds are produced due to pressure differences.
- As warm air rises, it leaves behind pockets of low pressure, causing air to rush in from high pressure areas in order to equalize the pressure.
- Warm air is displaced by denser cold air.
- Wind power, also known as wind energy, is a renewable energy source and can be converted into mechanical or electrical energy.
- Some examples of the use of wind throughout history have been to propel sailboats, mill flour, run sawmills, move water, and produce electricity.

Essential Questions

- How do pressure differences in the atmosphere cause the movement of air?
- What is the difference between a windmill and a wind turbine?
- What are the best locations for windmills and wind turbines?
- What are the essential components of a windmill?
- What is the history of the use of windmills?
- What are the ways in which windmills can irrigate fields to promote the production of crops?
- What are the essential components of a wind turbine?
- What is the history of the use of wind turbines?
- What is the projected use of wind turbines locally, nationally, and globally?
- What are the advantages and disadvantages of using wind turbines to produce electricity?

Notes to the Teacher

This lesson focuses on the science and technology behind William's accomplishment in *The Boy Who Harnessed the Wind*. It is important to stress at the beginning that wind is a renewable energy source with less environmental impact than many other energy sources. Windmills and wind turbines (with rare exceptions) do not release emissions that pollute the air or water and do not require water for cooling purposes. Wind energy can help reduce the amount of greenhouse gases and other pollutants released by nonrenewable energy sources used for the generation of electricity.

The suggested order of the activities provided can be altered depending upon each teacher's approach to this unit and the time needed to perform the activities. The lesson has four parts, each taking a minimum of two class periods of 45 minutes to one hour. Each part takes a hands-on approach to learning, followed by individual and/or group analysis and class discussion of key concepts.

Since you are using hot plates and generating steam, please make sure students are careful and aware of the dangers of being careless. For Part 2 of the lesson, check each station to be sure that hotplates are set below 451° Fahrenheit, or 233° Celsius, the ignition temperature of paper.

For additional information on wind energy, refer to:

Wind Explained History of Wind Power
https://www.eia.gov/energyexplained/index.php?page=wind_history

History of U.S. Wind Energy
https://www.energy.gov/eere/wind/history-us-wind-energy

Wind Energy Timeline—From Persian Windmills Crushing Grains to Vesta's Wind Turbines Churning out 8 MW of Output
https://www.altenergymag.com/article/2015/04/wind-energy-timeline-%E2%80%93-from-persian-windmills-crushing-grains-to-vesta%E2%80%99s-wind-turbines-churning-out-8-mw-of-output/19496

The Iconic Windmills That Made the American West
https://www.atlasobscura.com/articles/windmills-water-pumping-museum-indiana

Wind Energy
https://www.nationalgeographic.org/encyclopedia/wind-energy/

Wind Power Fundamentals
http://web.mit.edu/windenergy/windweek/Presentations/Wind%20Energy%20101.pdf

How a Wind Powered Sawmill Works- AMAZING
https://www.youtube.com/watch?v=Q6FxG3ll-lw

Wind Explained Wind Energy and the Environment
https://www.eia.gov/energyexplained/index.php?page=wind_environment

Wind Explained Where Wind Power Is Harnessed
https://www.eia.gov/energyexplained/index.php?page=wind_where

Wind Resource Map
http://windeis.anl.gov/guide/maps/map2.html

Wind Projects Map
https://www.windpowerengineering.com/wind-project-map/

How a Windmill Pumps Water
https://aermotorwindmill.com/pages/how-a-windmill-works

Wind Turbine Design
http://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-design.html

Wind Turbine Components
http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wtrb/comp/index.htm

Animation: How a Wind Turbine Works
https://www.energy.gov/eere/wind/animation-how-wind-turbine-works

Wind Project Development
https://windexchange.energy.gov/projects

Part 1 of this lesson focuses on the history of wind power use beginning with ancient Egyptian sail boats through the development of windmills to the current wind turbines used to generate electricity. Before the first class session, make a copy of **Handout 1: The History of Wind Power** for each student**.** Each pair of students will need to have access to the Internet connected to a color printer, one tri-fold corrugated poster board, scissors, markers, and glue sticks. Using **Teacher Resource 1**, each group will research the use(s) of wind power in a specific time period, create a poster, and present the poster to the class. A rubric for this activity is found on **Teacher Resource 2.** You may wish to use it just for scoring or you may share it with your students so that they can do a self-evaluation.

Part 2 explores pressure differences in atmospheric gases and convection as the sun heats the Earth's surface in order to give students a basic understanding of pressure differences leading to local and regional wind patterns and their effect on windmills and wind turbines. Before starting this part of the lesson, make a copy of **Handout 2: Understanding Pressure Differences, Convection, and the Wind** for each student. If the activity is done as a teacher demonstration, the teacher and students must wear safety glasses and aprons. If the activity is done in small groups, students must wear safety goggles and aprons. See **Teacher Resource 3** for sample answers. Check each station to be sure that hotplates are set **below** 451° Fahrenheit, or 233° Celsius, the ignition temperature of paper.

Part 3 focuses on researching and identifying the components of windmills and horizontal axis wind turbines and the basic difference between horizontal and vertical axis wind turbines. Before the first class session, make a copy of **Handout 3: The Components of Windmills and Horizontal Axis Wind Turbines** for each student**.** During the first session, students will watch a short animation on the difference between horizontal axis wind turbines and vertical axis wind turbines and then begin to research the components of windmills and wind turbines. During the second and third session, students will continue to research the windmill and wind turbine components and create posters. A rubric for this activity is found on **Teacher Resource 4**. You may wish to use it just for scoring or you may share it with your students for self-evaluation.

Part 4 is the summative assessment which requires students to design and construct a simple replica of a water-pumping windmill and to research information about a wind farm in

their state or a nearby state. Before starting this part of the lesson, make a copy of **Handout 4: Windmill and Wind Turbine Summative Assessment** for each student. During the first two to three sessions, students will design, construct, and test the simple water-pumping windmill replicas created. During the later sessions, display all of the windmill replicas around the room and have each group demonstrate their water pumping simulation. Assign students to research a wind farm in their state or a nearby state, and have them create informational wind farm posters for presentation to the class. Teacher guidance and a rubric for assessment are found on **Teacher Resources 6 and 7**.

An extension activity you might want to try with your class is to run a computer simulation to design, test, and build a wind turbine using the 3M Wind Energy Virtual Lab at https://www.youngscientistlab.com/sites/default/files/interactives/wind-energy/.

Next Generation Science Standards addressed by this lesson

https://www.nextgenscience.org/search-standards

HS-ETS1-1 Engineering Design
Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-3 Engineering Design
Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3-2 Earth and Human Activity
Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

HS-PS3-3 Energy
Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ESS3-4 Earth and Human Activity
Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Common Core Science Standards Initiative

http://www.corestandards.org/ELA-Literacy/RST/introduction/
http://www.corestandards.org/ELA-Literacy/RST/9-10/
http://www.corestandards.org/ELA-Literacy/RST/11-12/

Key Ideas and Details:

CCSS.ELA-LITERACY.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.11-12.1
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

CCSS.ELA-LITERACY.RST.11-12.2
Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

CCSS.ELA-LITERACY.RST.11-12.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Craft and Structure:

CCSS.ELA-LITERACY.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 9-10 texts and topics*.

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

CCSS.ELA-LITERACY.RST.11-12.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

CCSS.ELA-LITERACY.RST.11-12.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Integration of Knowledge and Ideas:

CCSS.ELA-LITERACY.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

CCSS.ELA-LITERACY.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

CCSS.ELA-LITERACY.RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CCSS.ELA-LITERACY.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Duration of Lesson

Detailed completion of every part of the lesson will take several weeks. The procedures can easily be adapted to fit available time.

Assessments

Completion of posters

Completion of activity observation sheets

Completion of answers to questions

Group discussions

Windmill replica and wind farm poster (summative assessment)

Materials

For each part of the lesson a computer with a projector or an interactive board such as a smart board is needed.

For Part 1:

Computer, tablet or phone with Internet access

Color printer access

Tri-fold corrugated poster board or 22" x 28" (23" x 33") oak tag paper

Scissors

Glue

Markers

Handout 1: The History of Wind Power

Teacher Resource 1: The History of Wind Power (teacher notes)

Teacher Resource 2: Rubric for the History of Wind Power Poster

For Part 2:

Windmill spinner plant trellis or Mylar pinwheel (or similar)

Safety glasses and apron

Balloon

Saran Wrap™ or similar plastic wrap

Hot gloves or tongs

Erlenmeyer flask

Culture bowl (or similar)

Hot plate

Water and ice

Rubber band

2" wide masking tape

Cardboard tubes from toilet paper and paper towels

Small cardboard boxes; small tissue boxes work well.

Lightweight yarn or string

Index cards

Small object to use as a weight

Aluminum foil

Handout 2: Understanding Pressure Differences, Convection and the Wind

Teacher Resource 3: Answer Sheet for Handout 2

For Part 3:

Computer, tablet or phone with Internet access

Color printer access

22" by 28" or 23" x 33" oak tag paper

Scissors

Glue

Markers

Handout 3: The Components of Windmills and Horizontal Axis Wind Turbines

Teacher Resource 4: Rubric for The Components of Windmills and Horizontal Axis Wind Turbines Poster

Teacher Resource 5: Answer Sheet for Handout 3

For Part 4:

Safety glasses, aprons, and nitrile gloves

Windmill Spinner Plant Trellis or In The Breeze Classic Mylar Pinwheel (or similar)

Roofing nail

Hot glue gun

22–24 AWG bare copper wire

Wood skewers (or similar)

Scissors

Fan

Computer, tablet or phone with Internet access

Color printer access

22" by 28" or 23" x 33" oak tag paper

Markers

Glue

Handout 4: Windmill and Wind Turbine Summative Assessment

Teacher Resource 6: Guidance for Summative Assessment

Teacher Resource 7: Rubric for Windmill and Wind Turbine Summative Assessment

Procedure

Part 1: The History of Wind Power

1. Before class, calculate how many pairs of students you will have in your class and divide **Teacher Resource 1** into the same number of sections. Cut the handout into these sections.

2. When class begins, distribute copies of **Handout 1** and read through the background information, objective, and methods. Answer any student questions that may arise.

3. Arrange students into pairs and give each pair a section of the **Teacher Resource 1** timeline to research historical uses of wind power. (Note: Information on early wind power history varies due to a lack of recorded information for this time period and therefore is subject to interpretation of available evidence.)

4. Have each group use the Internet to research the topic(s) and prepare the poster while you circulate to supervise and answer questions.

5. After the students have completed their posters, have them present results to the class.

6. After each poster is presented, have students discuss as a whole class the information presented, using **Teacher Resource 2** as a guide for the discussion.

Part 2: Understanding Pressure Differences, Convection and the Wind

1. Before class, check to be sure that each station has the necessary supplies for the activity. (See Materials, above.)

2. Distribute copies of **Handout 2** and read through the background information, objectives, and methods. Answer any student questions that may arise.

3. Stress safety precautions when completing the activity in individual groups or as a teacher demonstration.

4. If students are working together, arrange them into pairs with each pair given the necessary prescribed materials. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials. Allow students sufficient time to set up the activity and begin, while you circulate to supervise and answer any additional questions.

5. Monitor Part B to make sure student set-ups are not in an area in which the ventilation system or door and window drafts will interfere with the activity.

6. Monitor Part C to allow all students use of the fan(s). If fans are not available, students can perform this part by blowing on the pinwheel.

7. Make sure each group completes the observation tables for Parts A, B and C.

8. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers. The group work will probably extend into the next class period. Then have the students discuss as a whole class the answers to the questions. See **Teacher Resource 3** for suggested answers to the questions.

9. [Optional demonstration:] Hold a lit match a few inches from the mouth of the air intake tube; then move it closer so that students can see the flame being pulled toward the box. This should not be attempted by the students.

Part 3: The Components of Windmills and Horizontal Axis Wind Turbines

1. Distribute copies of **Handout 3** and read through the background information, objectives, and methods. Arrange students into pairs and answer any student questions that may arise.

2. Have each group use the Internet to view the animation on horizontal wind turbines and vertical wind turbines, research their topic, and prepare their poster while you circulate to supervise and answer any additional questions. Note that there are several empty spaces at the bottom of the table of windmill components if you or the students wish to add additional components.

3. After the students have completed making their posters, have them present results to the class.

4. After each poster is presented, have students discuss as a whole class the information presented using **Teacher Resource 5** as a guide for the discussion.

Part 4: Windmill and Wind Turbine (Summative Assessment)

1. Before class, check to be sure that each station has the necessary supplies for the activity.

2. Distribute copies of **Handout 4** and read through the background information, objectives, and methods. Answer any student questions that may arise.

3. Stress safety precautions when completing the activity.

4. Arrange students into small groups with each group given the necessary prescribed materials. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials.

5. Allow students sufficient time to design and construct a replica of a simple water pumping windmill, while you circulate to supervise and answer any questions.

6. Display all of the windmill replicas around the room and have each group perform their water pumping simulation.

7. In the second part of the assessment, have each group use the Internet to run the wind turbine simulation, research a specific wind farm, and prepare their poster, while you circulate to supervise and answer any additional questions.

8. After the students have completed making their posters, have them present results to the class.

9. After each poster is presented, have students discuss as a whole class the information presented.

Handout 1

The History of Wind Power

Background Information

The power of the wind has been harnessed for thousands of years. Historians believe that beginning approximately in 5000 BCE, wind power was harnessed by ancient civilizations. Currently, wind power is being developed as a renewable source of energy to produce electricity.

Objective

To research the history of the use of wind power and develop a timeline of the use of wind power throughout the centuries.

Materials

Computer, tablet, or phone with Internet access
Color printer access
Tri-fold corrugated poster board or 22" x 28" (23" x 33") oak tag paper
Scissors
Glue
Markers

Methods

1. Using the Internet, research the use(s) of wind power during your assigned time in history.
2. Print pictures of any wind power machines researched. Be sure to clearly label pictures of wind power machines and their uses.
3. Create a poster that presents the use(s) of wind power during the time period you researched; it should include pictures, written explanation, and citations. Enlarge pictures if necessary so they will be visible to the class during your poster presentation. Make sure all sources of information and pictures are cited.
4. Present the poster to the class and discuss the use(s) of wind power machine(s) during the assigned time in history.

Teacher Resource 1 ▸ P.1 The History of Wind Power

Notes to the teacher:

- In recent years, some historians have opted to use religiously neutral abbreviations. BCE = Before Common Era replaces BC. CE = Common Era replaces AD.[1]
- There are some significant discrepancies in some of the early historical information on wind power which need to be taken into consideration when assessing student work.

BCE	
5000/3500	Wind energy used to propel boats along the Nile
3500	Wind-powered water pumps used in China
CE	
200/500–900	Windmills with woven-reed blades grinding grain in Persia and the Middle East
1100s	Wind pumps and windmills used extensively in Middle East and Europe for food production
1000/1300	Large wind pumps used by Dutch to drain lakes and marshes in the Rhine River Delta; first horizontal axis blade windmills
1600s	Dutch windmill designs introduced to New World
1600s/1800s	American colonists' windmills to grind grain, to pump water, and to cut wood at sawmills
1887	First windmill for generating electricity built in Scotland
1850s	US Wind Engine Company established
1890s	Wind power used for pumping water and electricity
1890s	Steel blades invented for windmills
1893	Wind power showcased at the Chicago World's Fair
1920s	Wind turbines producing electricity in rural regions of Great Plains; first vertical axis wind turbine invented
1930s	In Russia, first wind power turbine commercial power plant to produce electricity
1941	Largest wind turbine powered local utility in Vermont during WWII
1970	Interest renewed in wind power due to high gas prices; first offshore wind farm in world beginning operation off coast of Denmark
1977	The US Department of Energy (DOE) formed; National Renewable Energy Laboratory in operation
1978	President Jimmy Carter signs Public Utility Regulatory Policies Act of 1978 requiring companies to buy electricity from renewable energy sources

Teacher Resource 1 ▸ P.2 The History of Wind Power

1980s	First wind farm in the world built in New Hampshire, U.S., but considered a failed project
1981	National Aeronautics and Space Administration scientists (NASA) developing "The Viterna Method," used for predicting wind turbine performance
1990	The amount of electricity in the U.S. produced from wind power less than 1%
1991	U.K.'s first onshore wind farm with a capacity of 10 turbines supplying enough power for 2,700 homes
1992	Energy Policy Act in the U.S.; production tax credit to focus on renewable energy
1993	The National Wind Technology Center (NWTC) built to be the nation's premier wind energy technology research facility
2003	Legal compliance in Europe encouraging the use of wind energy; 70% of total global wind energy production found in Europe
2005	The updated Energy Policy Act in the U.S. with incentives for renewable energy sources
2008	The European Union's target for the U.K. government to increase contribution of renewables to 20% by 2020; the U.S. Department of Energy's goal of 20% Wind Energy by 2030 report; U.S. installed wind farms reaching 25.4 Gigawatts
2009	Wind energy providing 2% of the total global electricity usage
2011	The U.S. Department of Energy's National Offshore Wind Strategy, a plan to develop offshore wind energy in the U.S.
2012	U.S. installed wind farms reaching 60 gigawatts; wind energy power in 15 million homes in the U.S. as the primary renewable source of electricity
2013	With a $12 million investment from the U.S. Department of Energy, at the University of Maine, the world's first concrete-composite floating platform wind turbine
2014	Wind energy contributing 20-30% of the annual electricity demand in nations such as Denmark and Spain
2015	The U.S. Wind Vision Report showing that 35% wind energy usage possible by 2050
2016	The U.S. Bureau of Labor Statistics naming wind turbine service technician as the fastest growing job of the decade
2016	First commercial U.S. offshore wind farm, Block Island Wind Farm, operating off the coast of Rhode Island; start year for China's 13th Five-Year Plan for Energy Technology Innovation, including the study of wind power in order to establish large-scale wind farms
2018	China the world leader with approximately 187 gigawatts produced from wind power; U.S. installed wind farms surpassing 89 gigawatts, enough to power over 20 million homes; approximately 7% of U.S. electricity produced from wind power; Germany producing approximately 56 gigawatts of wind power
2020	China's goal to produce 210 gigawatts of grid connected wind energy

Teacher Resource 2

Rubric for the History of Wind Power Poster

Group Members: _____

Title of Poster: _____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Required Content	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates some of the required content elements.	Poster incorporates few or none of the required content elements.
Accuracy of Content	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Effectiveness	Poster provides an excellent understanding of the topic.	Poster lacks 1 important element associated with the topic, but still provides a good understanding.	Poster lacks 2 important elements associated with the topic and provides only a basic understanding.	Poster lacks 3 or more important elements associated with the topic and does not provide a basic understanding.
Graphics	All graphics on the poster are labeled and attractive, and they support the topic of the poster.	1–2 graphics on the poster are not attractive, but all are labeled and support the topic.	All graphics on the poster are attractive and labeled, but a few do not support the topic.	Many graphics on the poster are unattractive and/or are not labeled and/or do not support the topic.
Formatting	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1–2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly on the poster.
Grammar	Poster has no misspellings and no grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Citations	All information and graphics in the poster are properly source cited.	1–2 pieces of information and/ or graphics in the poster are not properly source cited.	3-–4 pieces of information and/or graphics in the poster are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

Handout 2 ▸ P.1

Understanding Pressure Differences, Convection, and the Wind

Background Information

Pressure differences in atmospheric gases as the sun heats the Earth's surface and atmosphere drive convection and cause both local and atmospheric wind patterns. In this activity, you will be using steam generated by boiling water to examine pressure differences. This allows for greater pressure differences than just using air alone. You should be aware that, in spite of the lack of water, the physics of wind and pressure over a dry desert involves very similar mechanisms.

Objectives

To observe the movement of gases due to pressure increases and decreases
To simulate the effect of varying wind direction and speed on windmills

Materials

Windmill spinner plant trellis or Mylar pinwheel (or similar)
Safety glasses and apron
Balloon
Saran Wrap™ (or similar plastic wrap)
Plastic pinwheel or metal garden windmill
Hot gloves or tongs
Erlenmeyer flask
Culture bowl (or similar)
Hot plate
Rubber band
2" wide masking tape
1 toilet paper cardboard tube
1 paper towel cardboard tube
1 small cardboard box, slightly smaller than your hotplate surface. (A small tissue box works well.)
Lightweight yarn or string
Index card
Small weight
Aluminum foil

Handout 2 ▸ P.2

Understanding Pressure Differences, Convection, and the Wind

Methods

Part A

1. Fill an Erlenmeyer flask ½ full with tap water
2. Tightly seal the flask with a balloon.
3. Place the flask on a hot plate and turn on the hot plate to high.
4. After the water in the flask has boiled for 10–15 minutes, sketch and record observations in Table 1, Part A.
5. Turn off the hot plate.
6. Using hot gloves or tongs, remove the Erlenmeyer flask from the hot plate.
7. After the water in the Erlenmeyer flask cools, sketch and record observations in Table 1, Part A.
8. Repeat steps 1–7 using plastic wrap and a rubber band to tightly seal the flask.

Part B:

1. Cut a hole in the bottom of the box to allow heat to enter rapidly. If you are using a tissue box, the hole is the right size, but be sure to remove any plastic.
2. On the opposite side (the top), place the end of the toilet paper tube on the box, trace around it, and cut out a hole. Push the toilet paper tube a half inch into the hole; it should fit snugly in the hole. Any leaks can be covered with masking tape. (This is your chimney.)
3. On the side of the box, place the end of the paper towel tube on the box, trace around it, and cut out a hole. Push the paper towel tube a half inch into the hole; it should fit snugly in the hole. Any leaks can be covered with masking tape. (This is your air intake pipe.)
4. Cut about 18 inches of light string or yarn. Cut a square from the index card large enough that it will just cover the end of the paper towel tube. Affix the string to the card with a small piece of masking tape.
5. Place a square of aluminum foil on the hotplate to protect its surface.
6. Place the box with the chimney pointed up on the hotplate. Make sure the end of the paper towel tube is well off to the side of the hotplate. Add a small weight on top of the box to make sure the bottom is flush with the aluminum foil on the hotplate. Without turning the hotplate on, dangle the card a half inch away from the open end of the paper towel tube.
7. Turn the hotplate on and set it to 400° Fahrenheit (204° Celsius); do not exceed this temperature. Again dangle the card a half inch away from the open end of the paper towel tube. See if you can get it to "stick" and block the end of the tube.

Handout 2 ▸ P.3

Understanding Pressure Differences, Convection, and the Wind

Part C:

1. Place a plastic pinwheel in an Erlenmeyer flask so that it is supported with masking tape and stands upright. (A metal garden windmill may also be used.)
2. Place a fan 1 meter away from the pinwheel.
3. Turn the fan on low.
4. Move the fan so that it strikes the pinwheel at different angles at the same distance.
5. Orient the pinwheel so that it directly faces the fan at varying distances.
6. Record observations in Table 3, Part C.

Handout 2 ▸ P.4

Understanding Pressure Differences, Convection, and the Wind

Observations:

Sketch and describe what happened in Part A of the exploration

Table 1—Part A	
Balloon covered boiling water flask	**Plastic wrap covered boiling water flask**
Balloon covered flask after the water has cooled	**Plastic wrap covered flask after the water has cooled**

Handout 2 ▸ P.5

Understanding Pressure Differences, Convection, and the Wind

Table 2—Part B: Sketch and Observations of Index Card	
When hotplate was off	**When hotplate was on**

Handout 2 ▸ p.6

Understanding Pressure Differences, Convection, and the Wind

Table 3—Part C

Observations of Pinwheel Placed at Various Angles and Distances from a Fan

Handout 2 ▸ P.7

Understanding Pressure Differences, Convection, and the Wind

Conclusion:

Discuss the following questions with your group members and record your answers in the spaces provided.

1. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was heated? Explain your answer.

2. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was cooled? Explain your answer.

3. How is the movement of the air demonstrated by the behavior of the index card in Part B similar to air flow caused by the heating and cooling of the Earth's surface? Does the temperature difference of the air coming from the chimney and that entering the paper towel tube play any role?

4. In Part C, what caused the changes observed in the pinwheel when the fan was moved to strike the pinwheel at different angles and at different distances?

5. How do the observations in Part C relate to the positioning of windmills and wind turbines?

Teacher Resource 3 ▸ p.1 Answer Sheet for Handout 2

Note: Students have varying levels of understanding and answers should be discussed and clarified by the teacher.

1. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was heated? Explain your answer.

- The balloon and plastic wrap expanded above the rim of the flask as the water was heated.
- As water was heated, water molecules moved faster and farther apart and some went from a liquid to a gaseous state expanding outward into the balloon and plastic wrap causing them to expand.
- As the pressure in the flask increased, the expansion of gaseous water molecules to reach equilibrium pressed against the balloon and plastic wrap, causing them to expand and stretch outward from the rim of the flask.

2. In Part A, what happened to the balloon and plastic wrap on top of the flask as the water was cooled? Explain your answer.

- The balloon collapsed and the plastic wrap contracted below the rim of the flask as the water was cooled.
- As water was cooled, water molecules moved more slowly and the pressure in the flask decreased.
- As the pressure in the flask decreased when the water cooled, the plastic wrap was drawn into the flask as pressure was equalized.

3. How is the movement of the air demonstrated by the behavior of the index card in Part B similar to air flow caused by the heating and cooling of the Earth's surface? Does the temperature difference of the air coming from the chimney and that entering the paper towel tube play any role?

- Differences in the heating and cooling of the Earth cause differences in air pressure.
- As hot air rises, pressure is lowered and movement of molecules is seen when cooler air rushes in to equalize pressure.
- Denser cold air displaces warm air.
- Differences in pressure cause molecules to move from areas of high pressure to areas of low pressure.
- Air moves from areas of high pressure to areas of low pressure, causing the formation of wind.
- Rising air due to heating lowers surface pressure, creating a pressure gradient that causes air to move from higher pressure to the lower pressure area created by the rising air. The corrective force that equalizes the pressure differences is wind.
- The temperature difference between the chimney air and that entering the paper towel tube is important as the incoming air is cooler and denser, and hence rushes in to displace the hot air exiting the chimney.

Teacher Resource 3 ▸ p.2 Answer Sheet for Handout 2

4. In Part C, what caused the changes observed in the pinwheel when the fan was moved to strike the pinwheel at different angles and at different distances?

- As the pinwheel was moved away from the fan, the forces causing rotation of the pinwheel decreased in magnitude. Eventually, the forces were not adequate to move the pinwheel blades at all.
- As the pinwheel was moved at different angles to the fan, the differences in air movement between the fan and pinwheel caused the pinwheel movement to decrease, and at some angles the pinwheel did not move at all.
- When the artificial wind produced by the fan hit the pinwheel blades at different angles (called the angle of attack), the speed of the pinwheel blade varied.

5. How do the observations in Parts A, B and C relate to the positioning of windmills and wind turbines?

- Windmills and wind turbines need to be positioned in areas that produce sustained winds of sufficient speed during the year.
- If regional air pressure differences are insufficient, wind speeds will be less than needed to move the blades on windmills or wind turbines.
- Wind power is not converted to 100% efficiency; no turbine can capture more than 59.3% of the kinetic energy in wind. Therefore, windmills and wind turbines must be placed in areas in which the kinetic energy of the wind can be converted into the maximum amount of mechanical energy for irrigation, producing electricity, etc.

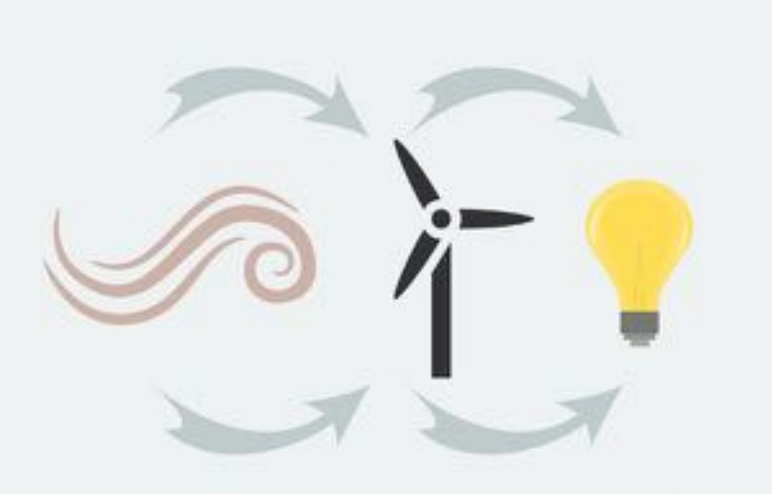


Image source: https://www.publicdomainpictures.net/en/view-image.php?image=290782&picture=wind-energy

Handout 3 ▸ P.1

The Components of Windmills and Horizontal Axis Wind Turbines

Background Information

Traditional windmills provided mechanical energy to grind grain or pump water. Modern wind turbines are typically used to generate electricity.

Both traditional windmills and modern wind turbines use blades to harness the wind's kinetic energy. As the air flows over the blades on windmills and wind turbines, the blades begin to turn and the kinetic energy of wind is converted to mechanical energy.

Objectives

To gain a basic understanding of the difference in movement between horizontal axis wind turbines and vertical axis wind turbines.

To research the components of windmills and horizontal axis wind turbines.

Materials

Computer, tablet or phone with Internet access
Color printer access
22" by 28" or 23" x 33" oak tag paper
Scissors
Glue
Markers

Methods:

1. Using the Internet, view the following animation in order to understand a basic difference in the movement of horizontal axis wind turbines and vertical axis wind turbines:
   https://fr.wikipedia.org/wiki/Fichier:HAWT_and_VAWTs_in_operation_large.gif
2. Using resources found on the Internet, define the terms listed in Table 1 on the next page.
3. Using the Internet, find pictures of windmills and wind turbines that could be used to label windmill and wind turbine components found in Table 1. (Your teacher may add additional terms.)
4. Create a poster that clearly identifies the components of the windmill and wind turbine pictures chosen in Step 3.

Handout 3 ▸ P.2

The Components of Windmills and Horizontal Axis Wind Turbines

Components of Windmills and Wind Turbines	
Component	**Definition**
Access Ladder	
Aeromotor Water Pump/Water Pump	
Anemometer	
Blade Pitch Control	
Brake	
Gear Box	
Generator	
Nacelle	
Rotor Blade/Fan	
Rotor Hub	
Shaft	
Sucker Rod	
Tower	
Wind Orientation Control/Yaw Control	

Teacher Resource 4

Rubric for The Components of Windmills and Horizontal Axis Wind Turbines Poster

Group Members:_____

Title of Poster:_____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Required Content	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates some of the required content elements.	Poster incorporates few or none of the required content elements.
Accuracy of Content	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Effectiveness	Poster provides an excellent understanding of the topic.	Poster lacks 1 important element associated with the topic, but still provides a good understanding.	Poster lacks 2 important elements associated with the topic but provides a basic understanding.	Poster lacks 3 or more important elements associated with the topic and does not provide a basic understanding.
Graphics	All graphics on the poster are labeled, attractive, and support the topic of the poster.	1–2 graphics on the poster are not attractive, but all are labeled and support the topic.	All graphics on the poster are attractive and labeled, but a few do not support the topic.	Many graphics on the poster are unattractive and/or are not labeled and/or do not support the topic.
Formatting	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1–2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly on the poster.
Grammar	Poster has no misspellings and/or grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Citations	All information and graphics in the poster are properly source cited.	1–2 pieces of information and/or graphics in the poster are not properly source cited.	3-–4 pieces of information and/or graphics in the poster are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

Teacher Resource 5

Answer Sheet for Handout 3

Components of Windmills and Wind Turbines	
Access Ladder	Can be up to 300 feet; provides access to service equipment in upper section of windmills and wind turbines.
Aeromotor Water Pump/ Water Pump	Wind water pumps in the past were mechanical mechanisms located on top of a wooden tower that pumped water for livestock and irrigation. The motor for a centrifugal electric water pump is driven by the electrical output from the wind turbine's alternator. Windmill generated electric pumping systems can provide a cost-effective alternative to small diesel pumps for both drinking water and small plot irrigation.
Anemometer	An anemometer measures wind speed and direction and is placed at the top of wind turbines to control the blades in order to ensure maximum efficiency.
Blade Pitch Control	Technology used to control the angle of the wind turbine blades, thereby the angle of attack relative to the angle of the wind.
Brake	Prevents over-speed and provides the ability to stop the blades.
Gear Box	Multiplies the wind turbine's speed and transmits it to the power of the generator.
Generator	Converts mechanical power to electrical power.
Nacelle	Contains key components of the wind turbine; such as the gearbox and electric generator.
Rotor Blade/Fan	Capture the wind and transfer its power to the rotor hub.
Rotor Hub	Connects blades to the main shaft to drive the gearbox and generator.
Shaft	When the rotor spins, the shaft also spins, transferring mechanical energy into rotational energy.
Sucker Rod	Gears convert rotary motion to an up-and-down motion which drives a long sucker rod/ pump rod up and down inside a cylinder. Water is alternately drawn into and expelled from the cylinder. Flow direction is controlled by check valves.
Tower	Carries the nacelle and rotor.
Wind Orientation Control/ Yaw Control	Uses electrical motors to turn the rotors against the wind.

Handout 4

Windmill and Wind Turbine Summative Assessment

Objectives

To build a simple replica of a water pumping windmill using the materials provided

To research a wind farm in your state or the closest wind farm in another state

Materials

Safety glasses, apron, and nitrile gloves
Windmill spinner plant trellis or Mylar pinwheel (or similar)
Roofing nail
Hot glue gun
22–24 AWG bare copper wire
Wood skewers (or similar).
Scissors
Fan
Computer, tablet or phone with Internet access
Color printer access
22" by 28" or 23" x 33" oak tag paper
Markers
Glue

Methods

1. Using information learned previously in this lesson, design and construct a replica of a simple water pumping windmill. The simple windmill must simulate the movement of the sucker rod, but will not show the movement of water.

2. Research a wind farm in the state or the closest windfarm in another state. Be sure to include:

- the name and location of the wind farm
- picture(s) of the wind farm
- the number of wind turbines in the wind farm
- the size of the wind turbines
- the capacity of the wind turbines
- the benefits of wind energy
- the negative impacts of wind energy

3. Create a poster containing the information from Step 2.

Teacher Resource 6 ▸ P.1 Guidance for Summative Assessment

Student designs and simulated windmills will vary, but should show the sucker rod movement up and down within a pipe. Depending upon the level of the class, the design and simulated windmill can be more complex and show the generation of electricity. Websites such as: https://www.popularmechanics.com/science/environment/how-to/g118/make-your-own-miniature-wind-turbine/ can assist students.

Sample research answer:

Groton Wind Farm

https://www.epsilonassociates.com/groton-wind-farm

Groton Wind Power Project

https://en.wikipedia.org/wiki/Groton_Wind_Power_Project

Name of Wind Farm and Location:

Onshore

Site Area: 4,180 acres

Iberdrola Renewables' Groton Wind Farm

Grafton County

Groton, New Hampshire

Pictures:

https://www.epsilonassociates.com/groton-wind-farm?lightbox=imagectd

https://www.epsilonassociates.com/groton-wind-farm?lightbox=image15yu

Number of Wind Turbines:

24 Gamesa wind turbines

Size of Wind turbines:

Hub height: 78 meters (256 ft.)

Rotor diameter: 87 meters (285 ft.)

Teacher Resource 6 ▸ p.2 Guidance for Summative Assessment

Capacity of the Wind Turbines:

Each turbine has a nominal power rating (sometimes called nameplate) of 2 megawatts (MW) for a total of 48 MW.

Annual net energy output: 144–158 gigawatt hours (GWh)

Advantages of Wind Energy

Sustainable energy source

Economic benefits:

Direct and indirect employment opportunities

Land lease/purchase payments

Lower tax rates

Lower electricity rates

Challenges and Negative Impacts of Wind Energy

Good wind sites are often far from cities

Can have a negative impact on flying wildlife

Catastrophic wind turbine failure and public safety

Sound impacts

Negative property value impacts

Shadow flickering across the ground and nearby structures

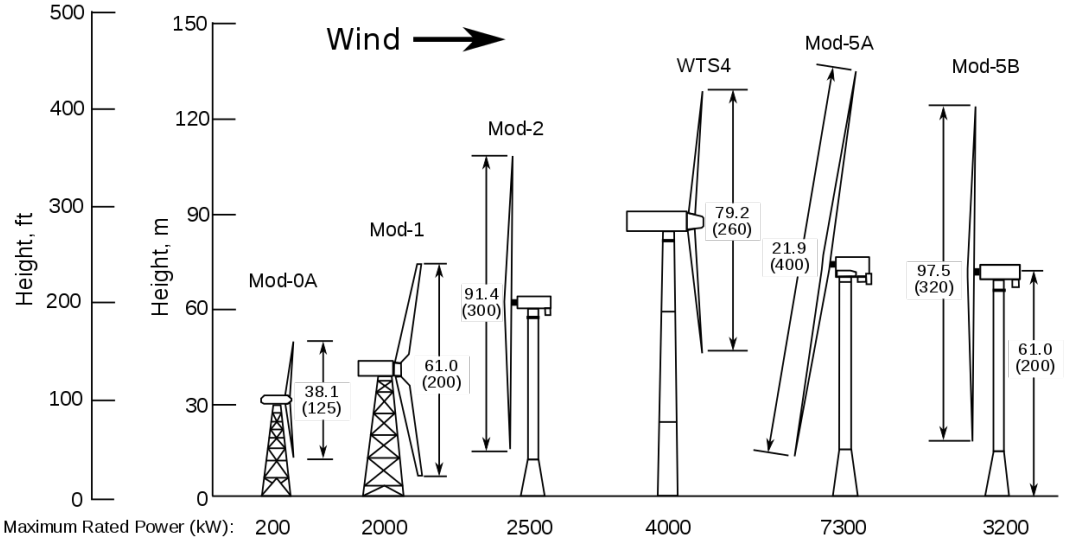
Communication and radar interference

Alteration of neighboring community views

Sea wind farms may be a safety issue for boats at night

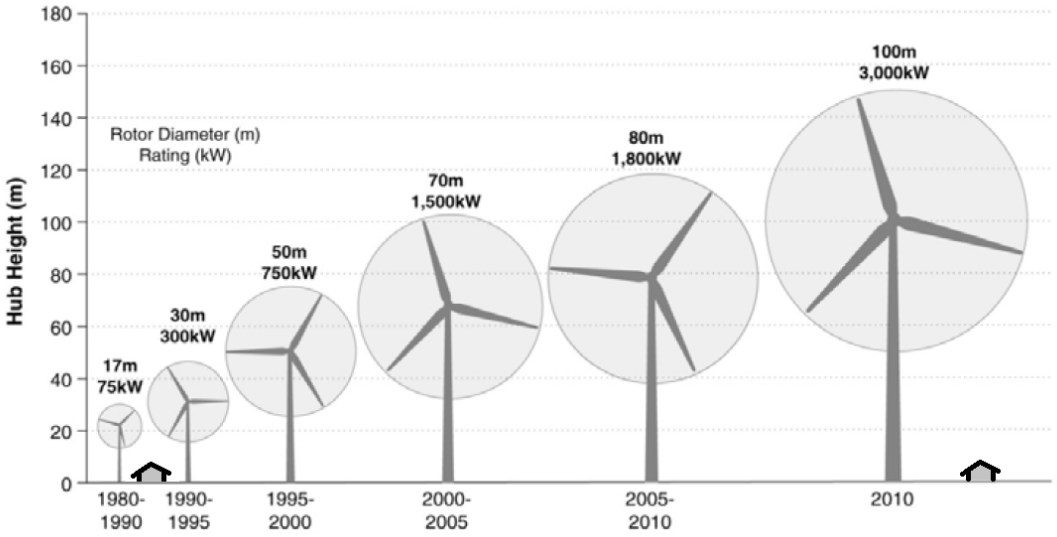
Community support (Example: New Hampshire residents have mixed feelings on wind farms: https://www.wmur.com/article/new-hampshire-residents-have-mixed-feelings-on-wind-farms-1/5182800)

Teacher Resource 6 ▸ p.3 Guidance for Summative Assessment



Department of Energy and NASA 1995 Comparison of Wind Generators

https://commons.wikimedia.org/wiki/File:Wind_generator_comparison.svg



Wind Turbine Size Increase 1980–2010

https://commons.wikimedia.org/wiki/File:Wind_turbine_size_increase_1980-2010.png

Teacher Resource 7

Rubric for Windmill and Wind Turbine Summative Assessment

Group Members:_____

Category	Excellent: 4	Good: 3	Satisfactory: 2	Needs Improvement: 1
Windmill Replica **Originality and Creativity**	Innovative approach. Exceeds expectations for students' skill level.	Students adapt others' ideas and show some originality. Meets expectations for students' skill level.	Students adapt others' ideas but show very little originality. Does not meet students' skill level.	No originality shown. Minimum effort exhibited.
Windmill Replica **Quality**	Superior craftsmanship and attention to detail.	Some craftsmanship and attention to detail.	Project lacks quality and details were overlooked.	Project is sloppy and lacks detail.
Windmill Replica **Function**	Windmill replica functions extraordinarily well with increasing levels of stress.	Windmill replica functions well with increasing levels of stress.	Windmill replica functions well, but begins to deteriorate under increasing levels of stress.	Windmill replica completely fails under normal levels of stress.
Wind Farm Poster **Required Content**	Poster incorporates all required content along with supplemental information.	Poster incorporates all required content.	Poster incorporates many of the required content elements.	Poster incorporates few or none of the required content elements.
Wind Farm Poster **Accuracy of Content**	All content in the poster is accurate.	1 content component in the poster is inaccurate.	2 content components in the poster are inaccurate.	3 or more content components in the poster are inaccurate.
Wind Farm Poster **Formatting**	All required content components are clearly labeled and easily visible on the poster. Information is sequenced correctly.	All required content components are labeled, but not clearly visible on the poster. Information is sequenced correctly.	1-2 required content components are not labeled on the poster. Information is sequenced correctly.	More than 2 content components are not labeled and/or information is not sequenced correctly.
Wind Farm Poster **Grammar**	Poster has no misspellings and/or grammatical errors.	Poster has 1–2 misspellings and/or grammatical errors.	Poster has 3–4 misspellings and/or grammatical errors.	Poster has more than 4 misspellings and/or grammatical errors.
Wind Farm Poster **Citations**	All information and graphics in the poster are properly source cited.	1–2 pieces of information are not properly source cited.	3–4 pieces of information and/or graphics are not properly source cited.	More than 4 pieces of information and/or graphics in the poster are not properly source cited.

Generating Electricity: Discount Store Physics

Enduring Understandings

- Electric and magnetic forces underlie many everyday interactions.
- Many technological devices convert energy from one form to another, more useful form.
- Technological devices are designed and built by humans, and so they can be taken apart and analyzed by humans.
- With ingenuity, technological devices can be reused for purposes other than originally intended.

Essential Questions

- What do electric and magnetic interactions reveal about the atomic scale properties of materials?
- How do circuits convert energy from one form to another?
- How does an electric motor use the relationship between electric and magnetic forces to convert energy supplied by an electric current into mechanical energy?

Notes to the Teacher

If you want to make it, all you have to do is try.

—William Kamkwamba

The activities in this lessons are designed to get students thinking about electric and magnetic interactions, simple circuits, and common consumer devices that use electromagnetism in one way or another. The themes are exploration, troubleshooting, and qualitative analysis. In some places, the instructions are left deliberately vague because there are multiple good ways (and plenty of bad ways) to do each activity. Encourage your students to explore different ways of making their devices work. Remind them that not all of William Kamkwamba's experiments succeeded. The ones that did work usually involved several iterations and missteps along the way.

The lesson is by no means a complete qualitative introduction to electrostatics or to circuits. Several important experiments from the typical introductory sequence are missing. For example, none of the activities explore induced charge, and although students work with DC motors, they don't explore electromagnetic induction directly, e.g., with bolts wound with wire.

Of course, you can also use more specialized, higher-quality equipment in the activities you do with your students. To make more advanced circuits with more components such as capacitors, resistors, transistors, and so on, it's cheaper, easier, and more effective to buy in bulk from an online supplier--but there are advantages to the "discount store" theme:

- It is in keeping with the spirit of the film, emphasizing both thrift and creative use of materials.
- Students work with "real" devices, not devices custom made for education. These devices cease to be "magic" black boxes whose inner workings can only be understood by a select few.
- It encourages breaking the mold of functional fixedness in the minds of students. Objects can be repurposed for something other than they were intended.
- Because of the low cost, you can make more equipment available to students—and if something breaks, yit can be affordably replaced.
- Students can bring their labs home with them, or even obtain the materials on their own. One advantage to a homework lab is that it allows for more exploration. Of course, since you won't supervise those labs, choose activities carefully, and reinforce good safety practices.

The lesson is suitable for any of the following groups:

- A middle school physical science class
- A ninth-grade conceptual physics course
- An intro to circuits activity for a high school engineering course or robotics club
- A summer project for students entering an Honors or AP Physics course
- Home-schooled students at middle or high school levels

Note that the amount of time required for each activity can vary greatly from group to group. It is also possible to conduct one or more of the experiments as a teacher demonstration.

Activity 1

The first part of the lesson introduces students to the concept of energy and delineates a number of different types of energy. Students experiment with using balloons to test the differences between conductors and insulators. This is of course not the only way to introduce electrostatics. Any selection of materials from the triboelectric series can work. Another fun, quick demonstration is to show that a stream of water from a faucet is attracted by a charged object. A good resource for ideas about activities in electrostatics is *the Physics Classroom* (https://www.physicsclassroom.com/class/estatics).

You may find it useful to project the multiple-choice problems here and elsewhere in front of the class, to better generate discussions. Of course, don't give answers before the students have had a chance to test their predictions. It should go without saying, but please try all the activities yourself before you have your students do them. You are also encouraged to dismantle some of the devices in the Extension Activities—quite a lot of fun—and if you enjoy it, your students will pick up on that excitement.

Activity 2

The second activity (**Handouts 3** and **4**) is similar to the "sticky tape" activity near the beginning of the E&M sequence from the American Modeling Teacher's Association (AMTA) at www.modelinginstruction.org; this site has additional activities to provide a more thorough investigation. Note that electrical tape seems to work better for this activity than Scotch™ tape. The tape is easier to manipulate, and it holds its charge longer.

This lesson deliberately avoids the terms "positive" and "negative" until the very end. It is preferable not to use those words until you discuss the results. Emphasize that the assigning of a negative charge to the electron is merely a convention. Many students operate under the assumption that there is some fundamental requirement that protons have positive charge and electrons negative charge.

For many students, their only experience with electrostatics is the attraction due to polarization. They are often surprised to find out that electrostatic forces can be repulsive. Even though most students have heard there are two different types of charge, many of them have not made the connection between this idea and the behavior of macroscopic objects.

Note that in some buildings, the metal structure may change the local magnetic field to point in a different direction from the Earth's intrinsic magnetic field. However, even then, the magnetized screwdrivers should still align with one another. (Of course, test it beforehand!) The main point still stands: to illustrate the existence of a magnetic field.

Hanging the screwdrivers with long thread in Step 9 of **Handout 4** is necessary because the torque on the screwdrivers due to the Earth's magnetic field is quite small. If the screwdrivers were just on a table, there would be too much friction to see anything happen.

While it may seem to be an elementary activity, I strongly recommend it. Arnold Arons describes the conceptual challenges concerning magnets faced by most students [Arons, Section 6.6; see Additional Resources below]. This specific activity is also detailed in Arons. Some of the main points:

- Most students have played with common refrigerator magnets, but many have never encountered magnet-magnet repulsion.
- While many students know what a compass does, they don't think of the tiny compass needle as a magnet, even if they've been told so.
- Even if students have heard of magnetic poles before, they often think of them as somehow the same as electric positive and negative charges.

Another good demonstration is to carefully cut one of the magnetized screwdrivers crosswise into two pieces. You can then show that each piece is itself a magnet with two poles. Magnetic poles cannot be separated – all magnets are bipolar.

The screwdrivers are not sensitive enough to easily show the vertical component of the magnetic field – the Earth's magnetic field points diagonally down in much of the Northern Hemisphere. However, they at least partially show the three-dimensional nature of the field, given that all the magnetized screwdrivers point in roughly the same direction, regardless of vertical or horizontal location in the room.

More broadly, this activity shows students that, with care, you can discover things that are not readily apparent. The force exerted by the Earth's magnetic field is not strong compared to everyday forces, and yet it's everywhere around us, all the time.

A good follow-up is any set of activities that explores qualitatively how polarization, charge transfer, and induced charge work in a dielectric on an atomic scale. For example, the AMTA physics modeling materials guide students to sketch each of these phenomena in several different scenarios.

Activity 3

The "interlude" on **Handout 5** is simply preparation for the next activities. The wire in the wire set can be challenging to work with. It is not very flexible, and it also tangles easily. Wire is typically reasonable in cost, so it is recommended that higher-quality copper wire is used if possible. If you use wire with a clear lacquer instead of a plastic coating, have students sand the lacquer off the ends with fine sandpaper rather than stripping the wire with the long nose pliers.

Activity 4

A common preconception among introductory physics students is that the charge carriers are somehow "used up" in a circuit, whereas in reality they travel continuously around the circuit. Having the student struggle with **Handout 6** to figure out how to make a circuit work goes some distance towards dispelling this myth.

Another helpful activity to do in conjunction with this one is the class battery/bulb/wire challenge. Give each student or group one length of wire, one battery, and one incandescent light bulb. Challenge them to light the bulb with only these materials.

It's also worth telling the students that the drift speed of the electrons in a typical DC circuit is actually quite slow, on the order of tens or hundreds of *micrometers* per second. Many students are under the mistaken impression that electrons in a wire travel at or near the speed of light, whereas it is actually the electromagnetic wave that travels this quickly. (See Chris Baird's web page "What Is the Speed of Electricity?" at https://wtamu.edu/~cbaird/sq/2014/02/19/what-is-the-speed-of-electricity/ for an excellent analogy to help your students understand the difference.)

Activity 5

In this activity, students test what happens when different sizes of batteries are used. The water analogy at the end of **Handout 7** is a useful visualization for physics students at an introductory level, even though it becomes problematic later on when considering various phenomena such as electromagnetic induction in greater, more quantitative detail. One of the most difficult hurdles for student comprehension of circuits is visualization, so even slightly flawed analogies are worth using.

Activity 6

You may also do the usual introductory physics investigation, analogous to the one in **Handout 8**, with small incandescent light bulbs. The goal is to solidify in students' minds how these qualitative relationships arise because of the way the electric potential energy of the charge carriers changes throughout the circuit. Depending on the course, qualitative investigation of Ohmic and non-Ohmic resistive components can come later.

As mentioned in the references, Chabay and Sherwood have an excellent discussion of how the microscopic distribution of charge changes the potential gradient in a circuit during the first moments it is connected to an emf-providing device.

Activity 7

It is strongly recommend that you have your students make simple electromagnets with a large nail or bolt and some copper wire. The discount store wire is not quite up to the task, but you can substitute a couple of feet of thin, insulated copper wire. There are numerous resources online describing how to build a simple electromagnet; for example, *Build an Electromagnet* at http://sciencenetlinks.com/student-teacher-sheets/build-electromagnet/ or *Hands-on Activity: Creating an Electromagnet* at https://www.teachengineering.org/activities/view/cub_mag_lesson2_activity1.

Next Generation Science Standards addressed by this lesson

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

[Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.]

[Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

[Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.]

[Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

[Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically charged pith balls. Examples of investigations could include first-hand experiences or simulations.]

[Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.]

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

[Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.]

[Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

[Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.]

[Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

[Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.]

[Assessment Boundary: Assessment is limited to systems containing two objects.

Common Core Standards addressed by this lesson

Analyze proportional relationships and use them to solve real-world and mathematical problems.

7.RP.2. Recognize and represent proportional relationships between quantities.

- **a.** Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin.
- **b.** Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.
- **c.** Represent proportional relationships by equations. For example, if total cost t is proportional to the number n of items purchased at a constant price p, the relationship between the total cost and the number of items can be expressed as t = pn.
- **d.** Explain what a point (x, y) on the graph of a proportional relationship means in terms of the situation, with special attention to the points (0, 0) and (1, r) where r is the unit rate.

Use random sampling to draw inferences about a population.

7.SP.1. Understand that statistics can be used to gain information about a population by examining a sample of the population; generalizations about a population from a sample are valid only if the sample is representative of that population. Understand that random sampling tends to produce representative samples and support valid inferences.

7.SP.2. Use data from a random sample to draw inferences about a population with an unknown characteristic of interest. Generate multiple samples (or simulated samples) of the same size to gauge the variation in estimates or predictions. For example, estimate the mean word length in a book by randomly sampling words from the book; predict the winner of a school election based on randomly sampled survey data. Gauge how far off the estimate or prediction might be.

Reason quantitatively and use units to solve problems.

N-Q.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N-Q.2. Define appropriate quantities for the purpose of descriptive modeling.

N-Q.3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

Duration

Three to four class periods, or two extended lab periods.

Assessment

Student responses to multiple choice problems.

Discussions of predictions and results.

Construction of functioning devices.

Materials

Individual materials (one for each student)

Copies of **Handouts 1–9**

Safety goggles

Dish pan for storing lab materials

Roll of PVC electrical tape

All-purpose scissors (may also be shared among 3 to 4 students)

Precision screwdriver set with magnetized tips and flat bases (may also be shared among 3 to 4 students)

Eyeglass repair kit (with non-magnetized screwdrivers) (may also be shared among 3 to 4 students)

Craft storage box for storing small screws and odds and ends

Wire set

Paper towel holder

Long nose pliers (may also be shared among 3 to 4 students)

Personal mini fan

Package of six AA batteries

Package of binder clips

9V battery

Organizer case for storing batteries

Shared Materials (for up to 24 students)

1 bag of 25 latex balloons

1 box aluminum foil

1 package dental floss or sewing thread

8 packages of three D cell batteries

1 package six AAA batteries

1 package C cell batteries

(All materials could be found very affordably at online or in-person discount variety stores. Note that certain items are seasonal.)

Procedure

1. Start by asking the class to name things that they associate with the word *energy*, listing them on the board in your classroom. (It doesn't matter how outlandish a comment is—the idea is to brainstorm.) Use this as a springboard into a discussion centered around the question, "What is Energy?" Through gradual prompting, help students arrive at some of the important points about the general properties of energy. Also encourage them to classify the ways that energy can be stored. They don't have to get all the terminology right; the point is to get them thinking more precisely about concepts that they probably haven't given much thought to until now.

2. Distribute **Handout 1: What Is Energy?** and assign as reading for homework or allow time in class for reading. The discussion in Step 1 should solidify and organize their understanding of how energy is defined and classified. Wrap up the discussion by writing the following definition on the board for students to copy or by locating the definition of energy in your textbook for them to review:

   Energy is the ability to do work. It can be stored in various forms and transferred from place to place. Given a reference frame, an object moving or rotating with respect to that frame stores kinetic energy, and two or more interacting objects can store potential energy as they get closer together or farther apart. If we consider large collections of atoms and molecules, kinetic energy and potential energy are usually called thermal energy and chemical energy.

3. Review the safety precautions on **Handout 1** with students before beginning the activities. Ask students to explain why each item is important.

4. Distribute **Handout 2: About Clingy Things**, along with the materials listed on the handout. Assign students to work in small groups. Each time students reach a multiple-choice question here and elsewhere in the lesson, project it on screen. Solicit responses from the students and ask them to defend their choices. Have students clear their work areas.

5. Distribute **Handout 3: PVC Sandwich, Hold the Mayo**, along with the materials listed on the handout. Continue to have the students work in small groups. The results of this activity, when done correctly, will probably be surprising to many students. Make sure to dedicate time to a discussion of the implications. Finishing up to this point is near the maximum that can be accomplished in Day 1, for a 50- to 60-minute class period. Make sure students clean their work areas before moving on.

6. Distribute **Handout 4: You're Standing in a Field Somewhere**, along with the materials listed on the handout. Continue to have the students work in small groups. Once the students hang their screwdrivers, they may proceed to the activities in **Handout 5**.

7. Distribute **Handout 5: Interlude: Cutting and Stripping**, along with the materials listed on the handout. Continue to have the students work in small groups. Since this activity requires little discussion, students can start it as soon as they finish **Handout 4**. You can return to a class discussion of **Handout 4** once the screwdrivers have had a chance to settle. Another option is to assign the cutting and stripping of wires for homework. Make sure students clean their work areas before moving on.

8. Distribute **Handout 6: It's Hot, Please Close the Fan**, along with the materials listed on the handout. Continue to have the students work in small groups. Although there are no specific questions for the students to answer, it's worth taking the time to walk around and have different students trace the path that current follows in their circuits. This activity will probably take the class through the end of Day 2. Make sure students clean their work areas before moving on.

9. Distribute **Handout 7: Pumps and Tanks**, along with the materials listed on the handout. Continue to have the students work in small groups. It's worthwhile to spend a good bit of time discussing the questions in this activity and their implications. This is the first activity that truly requires visualization of what is going on in an electric circuit, which most students have a great deal of difficulty with at first. Make sure students clean their work areas before moving on.

10. Distribute **Handout 8: Series and Parallel**, along with the materials listed on the handout. Continue to have the students work in small groups. There are a lot of conceptual questions in this handout, so leave enough time for a discussion of each point. This activity will probably take the class to the end of Day 3, or even into Day 4. Make sure students clean their work areas before moving on.

11. Distribute **Handout 9: E&M—Epilogue**, along with the materials listed on the handout. This activity is intentionally open-ended, without many instructions provided. It is a chance for students to put their problem-solving skills and ingenuity to the test. This activity will probably take the class into Day 4 or to the end of Day 4. Make sure students clean their work areas when they are finished.

Extension Activities

Many small gadgets found at doiscount stores are worth taking apart and investigating. The cost constraints placed on the design of these objects lead to some interesting circuits. They must be simple and easy for workers to assemble. They must use an absolute minimum of material, and at the lowest possible cost. It's hard not to admire the engineers who designed them. Perhaps as an unintended side effect, the workings end up relatively straightforward for a motivated student to understand.

LED String Lights

There are ten LEDs in this set. By trying a single 1.5-volt battery instead of two, students can see that LEDs require a certain minimum voltage in order to function. Even if they cut out a single LED and apply 1.5 V, the LED will not work, but with 3.0 V it will light. Students can also see that LEDs, like all diodes, are directional—they only function with a forward bias.

Solar Stake Light

This is a fascinating device. It is a very simple circuit, with only a solar panel, an inductor, a rechargeable battery, and a transistor-like device acting as an oscillator. The article *Hacking an LED solar garden light* at https://ez.analog.com/university-program/b/blogs/posts/hacking-an-led-solar-garden-light provides an excellent description of its workings and has several ideas for other projects with the device.

Mini Powered Speaker

This speaker contains an LED, a small audio amplifier (Texas Instruments, model number LM4871), and of course a speaker. The speaker is magnetic (instead of piezoelectric), and provides another illustration of a current producing a magnetic field. Since there is no rotation, the speaker's operation may be even easier for students to grasp than the motor's.

Ear Buds

Most students have used earbuds before. That alone makes it worth taking a pair apart, to investigate the workings, especially in comparison to the larger speaker. With care, students can find the small magnet inside each earbud, and note that the circuit is extremely simple: changes in the current and voltage cause the magnet to vibrate at different frequencies and amplitudes. With a powerful enough amplifier, you can also demonstrate to students that a speaker is a microphone in reverse.

Window and Door Alarm

This device contains a magnet, a reed switch, a transformer, and a piezo speaker. The speaker is not magnetic, of course, because it would interact with the sensitive reed switch, which is closed by the magnet.

Quite a lot of simple and curious devices that are worth dismantling can be found at various online or in-person discount stores. Two examples in the United States are Dollar General Corporation™ and Five Below Inc™. For more ideas, there are countless videos and blogs available online documenting hacking of inexpensive consumer electronic devices. Happy tinkering, and may not all your engineering be reverse!

Additional Resources

American Modeling Teacher's Association (AMTA) at https://modelinginstruction.org/
The modeling method of teaching physics has been used in the classroom by thousands of teachers for more than twenty years. By certain metrics, such as the Force Concept Inventory, it is one of the most effective ways of teaching physics. Many activities in this lesson are inspired partly or entirely by the modeling physics community. The author uses modeling methods in the physics classroom.

Arons, Arnold B. *Teaching Introductory Physics*. Wiley, 1997. Arnold Arons was one of the pioneers of physics education research. This encyclopedic work is an extraordinarily helpful reference for putting yourself in the mind of a beginning physics student. It details what preconceptions people have

before taking physics and describes strategies for effectively training students to think like physicists.

Atwater, Mary. *Using Energy*. Macmillan McGraw-Hill, 1995.
This book, William Kamkwamba's original inspiration, is unfortunately out of print. As of this writing, a few used copies are available online at ridiculous markups.

Chabay, Ruth W. and Sherwood, Bruce A. *Matter and Interactions*. 3rd ed., Wiley, 2011.
This text is an excellent resource for instructors and students. The book clearly describes and diagrams the multiple connections between the microscopic and macroscopic behavior of circuits, both conceptually and quantitatively.

Epstein, Lewis Carroll. *Thinking Physics Is Gedanken Physics*. Third ed., Insight Press, 2009.
This is an excellent source of puzzles in introductory physics. While the questions are phrased at a very introductory level, some of them are quite challenging, even for professional physicists! The multiple-choice problems in this lesson are inspired by Epstein's.

Hewitt, Paul G. *Conceptual Physics*. Eleventh ed., Pearson, 2010.
The classic conceptual physics text. It is a rare gem—a textbook you can just sit down and read, for pleasure.

Kamkwamba, William and Mealer, Bryan. *The Boy Who Harnessed the Wind*. HarperCollins, 2009.
Many more of Mr. Kamkwamba's experiments are detailed in the book than in the movie. He goes into great and entertaining detail about both his successes and his failures. If you decide to try to replicate some of his projects, be careful, as some of them are quite dangerous!

Mims, Forrest M. *Getting Started in Electronics*. Master Publishing, Inc., 2000.
This book describes exactly 100 circuit projects for the budding scientist or engineer to try. Half the book is devoted to explaining the operation of resistors, capacitors, LEDs, transistors, relays, speakers, and so on in an easy-to-understand way. The figures alone are more than worth the price of the book.

Handout 1 ▸ P. 1

What Is Energy?

Africans bend what little they have to their will every day. Using creativity, they overcome Africa's challenges. Where the world sees trash, Africa recycles. Where the world sees junk, Africa sees rebirth.

—Erik Hersman, quoted by William Kamkwamba in his book, *The Boy Who Harnessed the Wind*

I noticed a book I'd never seen, pushed into the shelf and slightly concealed. What is this? *I thought. Pulling it out, I saw it was an American textbook called* Using Energy, *and this book has since changed my life.*

—William Kamkwamba

In this lesson, you will dismantle, investigate, and build devices that convert energy from one form to another. Most, if not all, technology works by converting energy from a widely available form to a directly useful form. In the film *The Boy Who Harnessed the Wind*, William Kamkwamba repurposes many parts from old devices and from scrap heaps. In that spirit, you will be using low-cost parts whenever possible. Many of these are available from so-called "discount stores."

William Kamkwamba was originally inspired by the book *Using Energy* by Mary Atwater. What is energy? Perhaps it's best to start exploring energy by understanding what you can and can't do with it.

- You can't create new energy.
- You can't destroy existing energy.
- You ***can*** transfer energy from place to place.
- You ***can*** store energy.
- You ***can*** change the storage form of energy.

There are different names that we use for the various storage forms of energy. Objects can store energy by moving or by spinning. This is called **kinetic energy**. You have more kinetic energy when you're running than when you're standing still. A figure skater has more kinetic energy when spinning than when standing still.

Two or more massive objects can store energy when they're pulled apart. This is called **gravitational potential energy**. You and the Earth have more gravitational potential energy when you're on top of a tall mountain than when you're at sea level. That's because when you climbed the mountain, you increased the distance between you and most of the rest of the atoms on the Earth.

Springs can store energy when they're compressed or stretched out. This is called **spring potential energy**. Toy car launchers, NERF™ guns, pogo sticks, trampolines, and other such objects work by storing spring potential energy and then converting it to other forms of energy.

The total of kinetic energy, gravitational potential energy, and spring energy is sometimes called **mechanical energy**.

Handout 1 ▸ P. 2

What Is Energy?

Electrically charged objects (which we'll explore soon) can store energy when they're pulled apart or pushed together. This is called **electric potential energy**.

Two or more atoms can store energy when they're pulled apart, pushed together, or formed into different shapes. Although this is partly about electric potential energy on a small scale, this is usually called **chemical energy** when dealing with large collections of molecules, as we do in everyday life. You change chemical energy into other forms of energy all the time. For example, this happens when you burn something, when you eat food, and when you use a battery in any sort of device.

Atoms and molecules can store energy by shaking, spinning, bumping into each other, and moving from place to place. Although this is partly about kinetic energy on a small scale, this is usually called **thermal energy** when dealing with large collections of molecules, as we do in everyday life.. The temperature of an object tells you something about the average thermal energy of its atoms and molecules.

"Energy is all around you every day," it said. "Sometimes energy needs to be converted to another form before it is useful to us. How can we convert forms of energy? Read on and you'll see."

I read on.

—William Kamkwamba, quoting the book *Using Energy*

A Note About Safety

You must wear safety goggles for all experiments. There will occasionally be bits of metal and plastic flying about. Getting a small, sharp piece of metal in your eye will likely result in permanent damage. Act like a professional: wear eye protection!

Safety Precautions

I climbed to the top of the tower and, as usual, kicked off my flip-flops so I could get a better grip. But the wind was violent and angry, pushing the tower from side to side so much that I thought it would tip. I wrapped my legs through the rungs and held on for life. But in trying to keep my balance, I didn't notice the bicycle frame swinging forward along with the tower. The next gust of wind sent the blades straight into my hand and knocked me off balance. I slipped and nearly fell, grabbing hold of the rungs and cursing. Looking at my hand, I saw the blades had shaved the meat off three of my knuckles, which were now dripping blood that scattered with the wind.

—William Kamkwamba

Handout 1 ▸ P. 3

What Is Energy?

- Always wear your goggles.
- Keep your work area clean and free from debris.
- Take special care with flammable material, such as cardboard packaging.
- Keep batteries in an insulated container, such as a craft storage box or **organizer case**. Always put batteries away when not using them, ***even if only for a few minutes***. Do not keep any other materials with the batteries, especially flammable materials or metallic materials.
- Store spare bits of wire separately from batteries.
- Don't build anything that would produce a large current. Don't put more small batteries in a series larger than about 12 volts worth.
- Don't swallow batteries. Obviously. And yet in the United States alone, several people every year—mostly small children—receive permanent or fatal injuries after swallowing batteries. If a battery gets lodged in the wrong place, it can cause serious burns to internal organs. See the Poison Control website for button battery ingestion statistics at https://www.poison.org/battery/stats and the article "Batteries Cause Devastating Injuries" at https://www.poison.org/articles/button-batteries.
- Batteries are properly placed in a circuit with the positive end of one battery touching the negative end of the next battery. At one point, you will be asked to place two batteries the wrong way; only do this with two batteries as directed. Do not place a row of batteries in a circuit this way and then place one in the opposite direction. You can burst the battery casing and leak battery acid.

OK, after all those warnings, this may sound strange: don't be afraid to mess something up! It's part of the learning process. **If you're taking appropriate safety precautions**, the worst-case scenario is that you lose a few dollars' worth of equipment.

Disposal of batteries

In many places, small batteries are considered non-hazardous and may be disposed of in the trash. One exception to this is the state of California, which considers all batteries to be hazardous waste. Follow your local guidelines for battery disposal. See the Environmental Protection Agency guidelines at https://www.epa.gov/recycle/used-household-batteries for additional information.

Handout 2 ▸ P. 1

About Clingy Things

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 balloon from the bag of 25 latex balloons
1 piece of scrap paper
1 small square of aluminum foil

Procedure

Tear up a piece of scrap paper into small bits, roughly 5 mm across. Scatter the bits on a desk or table. Blow up a balloon and tie off the end. Rub the balloon on your hair. Hold the balloon over the bits of paper, with the side you rubbed closest to the bits of paper. Describe what happens.

You may have heard that objects are made of extremely small particles called **atoms**. Sometimes the atoms are clumped into small groups called **molecules**. The atoms themselves are made of other, smaller particles: **protons**, **neutrons**, and **electrons**.

In some materials, a few of the electrons can easily move from place to place, if they stay within the object. These materials are called **conductors**. (In a solid object, the protons and neutrons are always stuck, no matter what.) Most conductors are metals, but there are exceptions.

In some materials the electrons can't easily escape the atoms or molecules. These materials are called **insulators**.

Electrons are **electrically charged**, which means they can be pushed or pulled by electric forces. Paper is an insulator, so its electrons can't move all around the paper, but they can be jostled from place to place ***within*** the molecules they're stuck in.

By the way, electrons are ***not*** energy, but they can store energy, just like any other object. A moving electron stores kinetic energy. Two or more electrons can store electric potential energy. So can an electron and a proton, or a proton and another proton, or bigger groups of electrons and protons.

Handout 2 ▸ P. 2

About Clingy Things

When you rub the balloon on your hair, you're rubbing electrons off one surface and onto the other. This messes up the charge balance on you and the balloon. The balloon can now exert an electric force, so when you hold the balloon up to the bits of paper, it jostles the electrons around just a smidge. That smidge is enough that the electric force on the protons and electrons no longer quite cancels out.

Everything gets jostled around in just the right way so that the bits of paper are attracted to the balloon. The electrons rearrange themselves to try to "correct" the unbalanced charge on the balloon.

Imagine you do the same thing, but with bits of aluminum foil, instead of bits of paper. What will happen?

- ☐ **A.** The bits of aluminum foil will be attracted to the balloon.
- ☐ **B.** The bits of aluminum foil will be repelled by the balloon.
- ☐ **C.** Nothing will happen. The bits of aluminum foil will just sit there.

Now test your prediction. Briefly record what you tried and what happened.

Aluminum is a conductor. Some of the electrons can move around freely in the aluminum. Compared to the electrons in the bits of paper, the electrons in aluminum have even more freedom to move and attempt to "correct" the balloon's unbalanced charge. However, aluminum is more than twice as dense as paper, so it's harder to accelerate each bit.

Notice that you never rubbed the paper or the aluminum. The charges just jostled around a bit, but none of them left the material. This process is called **polarization**.

On the other hand, with the balloon and hair, you added or removed some charged particles from each object. When you charge objects by friction, each object gets an unbalanced amount of charge.

You saw that when you hold a charged object (balloon) up to a polarized object (paper, foil), the objects are attracted. Advertisers for dryer sheets call this "static cling."

Handout 3 ▸ P. 1

PVC Sandwich, Hold the Mayo

Materials

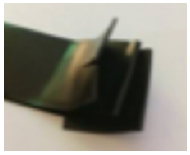
1 pair of safety goggles for each person
1 Dishpan for storing lab materials
1 roll of PVC electrical tape
1 pair of all-purpose scissors
1 balloon from the bag of 25 latex balloons

Procedure

1. Using a pair of scissors, cut off six pieces of PVC electrical tape, each about 15 cm long. (You don't need a ruler—just estimate.) Hang them off the edge of a desk or table to keep them organized. Fold over about 1 cm on one end of each strip, to form a non-sticky "handle."

2.  Place the longest two strips side by side on the surface of a desk or table, sticky side down. Run your finger over them a few times to make sure they're flat. We'll call these the **base strips**. They will stay in the same place for the entire activity.

3. Layer two more strips on top of the base strips, sticky side down. Run your finger over them to flatten them. We'll call these the **down strips**.

4.  Layer the last two strips on top of the down strips, and again run your finger over them to smooth them out. We'll call these the up strips. Find some way to mark the up strip in each three-layer sandwich. For example, poke a small hole in each up strip with a pen, or use a pair of scissors to make a small cut in their handles.

5. From one of the sandwiches, grab the up strip and down strip together by their handles. Peel them up together, trying to keep the base strip on the table. If the base strip comes up, just tear the base strip off and put it back on the table.

6. Pinch the up strip and down strip together with your fingers, and rub along their surfaces, as if you're squeezing the water out of a small sponge. Using both hands, tear the up strip and down strip away from each other.

7. Flip one strip over, so the sticky sides don't face each other. Bring the strips close together, but try not to let them touch. Briefly record what happened in your notebook. Then hang these up strip and down strips along the edge of your desk or table.

Handout 3 ▸ P. 2

PVC Sandwich, Hold the Mayo

8. Repeat steps 5–7 with the other three-layer sandwich. Briefly record what happened in your notebook. Hang this second set of up strip and down strips along the edge of your desk or table.

9. Now take the two up strips and bring them close together, without letting them touch. Then do the same thing with the two down strips. Briefly record what happened.

10. Hold a pen or pencil near each type of tape. Briefly record what happened.

11. Charge a balloon as you did in the previous activity. Bring it near each type of tape, without letting it touch. Briefly record what happened.

Handout 4 ▸ P. 1

You're Standing in a Field Somewhere…

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 precision screwdriver set
1 eyeglass repair kit
2 to 3 small screws, steel paperclips, or other small iron objects
1 craft storage box for storing small screws and odds and ends
1 balloon from the bag of 25 latex balloons
1 roll of PVC electrical tape
1 pair of all-purpose scissors
1 container of dental floss (or 1 roll of sewing thread)
1 unused classroom or large closet with a low ceiling and little air flow

Procedure

Work through the following procedure step-by-step. Don't jump ahead or read ahead until you have completed the step you are working on.

1. The screwdrivers in the precision screwdriver set are magnetized. This is to make it easier to pick up and manipulate small screws. Verify that the screwdrivers are magnetic by holding them up to a screw, a paperclip, or some other small metal object.

2. The screwdrivers from the eyeglass repair kit are not magnetized. How can you verify this? Try it, and briefly record what happened in your notebook.

3. Take out two magnetized screwdrivers. Balance one of them on your finger, parallel to the floor. Using your other hand, hold the tip of the other screwdriver next to the pointy end of the screwdriver on your fingertip. Briefly record what happened.

4. Now hold the opposite end of the metal part of one screwdriver up to the pointy end of the screwdriver that is balanced on your fingertip. (The "opposite end" of the metal part of the screwdriver is actually somewhere in the middle of the screwdriver.) Briefly record what happened.

5. Now hold the tip of one screwdriver up to the opposite end of the metal shaft of the screwdriver that is balanced on your fingertip. (This is roughly in the center of the screwdriver.) Briefly record what happened.

Handout 4 ▸ P. 2

You're Standing in a Field Somewhere…

All magnets have two sides to them, called **poles**. Somewhat arbitrarily, the poles of a magnet are called the north pole and the south pole. But they just as easily could have been called the red pole and the blue pole, or the truth side and the beauty side.

Opposite poles attract each other, and similar poles repel each other. Even if you cut a magnet into two pieces, each piece still has two poles. No one has ever seen just a north pole or just a south pole by itself, even though many scientists have looked very hard.

William Kamkwamba explains it better:

I also knew about the magnet's opposing sides. If you had two magnets, one side would always fight the other, refusing to stick together. However, flip one of the magnets over and it will snap to its fellow magnet.

6. Now choose your answer to this question: Are magnetic poles and electric charge the same thing?

- ☐ **A.** Yes, they're the same thing.
- ☐ **B.** No, they're completely unrelated.
- ☐ **C.** No, but they're related somehow.

Briefly explain your choice.

7. Blow up a balloon, then rub it against your hair or someone else's. Balance a magnetized screwdriver on your fingertip. Bring the charged side of the balloon close to the point end of the screwdriver. Then try the same thing, but with the balloon close to the other end of the screwdriver. Briefly record what happened.

8. Using PVC electrical tape, make a three-layer sandwich as you did in the previous activity. Pull off the "up" and "down" strips, then pull them apart. Remember to mark them somehow so you can tell them apart. Hang them from the edge of your table or desk. Bring one of the magnetized screwdrivers close to the "up" tape, then close to the "down" tape. Briefly record what happened.

Handout 4 ▸ P. 3

You're Standing in a Field Somewhere…

Are these observations enough to rule out one of the options in the last multiple-choice question? Explain.

9. Cut off a long (more than one meter) piece of dental floss or sewing thread. The longer, the better, but it can't be longer than the ceiling-to-floor distance. Find the point at which the screwdriver balances on your fingertip. Tie one end of the thread at this point, so that the screwdriver hangs roughly horizontally, parallel to the floor. Secure it with a small piece of PVC electrical tape.

Tape the other end of the thread to the ceiling. (If you need to stand on a ladder, chair, or table, have a classmate spot you.) Use PVC electrical tape, painter's tape, or other tape that comes off easily. Do not use clear "sticky tape," often referred to in the United States by the brand name Scotch Tape™.

Repeat with at least two other magnetized screwdrivers. Do the same with several non-magnetized screwdrivers from the eyeglass repair kit. Keep them spaced at least a meter apart. If you are working with other classmates, you may want to hang far more screwdrivers. The result will be more dramatic.

10. Now make your prediction: What will happen after you leave the room for a while?

- ☐ **A.** All the screwdrivers will line up with each other and about point the same way.
- ☐ **B.** None of the screwdrivers will line up. They'll all still point in random directions.
- ☐ **C.** Only the magnetic screwdrivers will line up with each other. They will point about the same way.
- ☐ **D.** Only the magnetic screwdrivers will line up with each other. Each one will point the opposite way from its nearest neighbor.

Explain your reasons for this prediction.

Then leave the room where the screwdrivers are hanging for at least ten minutes. Briefly record what happened when you return.

Handout 4 ▸ P. 4

You're Standing in a Field Somewhere…

Here is William Kamkwamba's explanation:

The north pole of the magnet will always attract the south pole, while two similar poles push away from each other. Because of its liquid iron core, the earth itself is a kind of large bar magnet, with magnetic north and south poles. Magnets, just like the earth, have natural magnetic fields that radiate between the poles. These lines are invisible, of course, but if you were to see them, they'd appear like the wings of a butterfly. One end of the bar magnet will always be pulled toward the magnetic north pole of the earth. This is how a compass works—inside there's a small bar magnet that finds north and keeps you from getting lost.

What do you think of Mr. Kamkwamba's assertion? Did you just make a room full of compasses?

11. For certain types of forces, you can figure out a size and direction for that force in ***every*** location. The physics term for this is a **field**.

- The Earth exerts a gravitational force on every object. Is there such a thing as a gravitational field? If so, where is it? Which way does it point? If not, why?

- Your arm can exert a force on other objects. Is there such a thing as an arm field? If so, where is it? Which way does it point? If not, why?

- Is the activity with the magnetic screwdrivers enough to tell which way the Earth's magnetic field points? Explain.

Handout 5

Interlude: Cutting and Stripping Wire

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 wire set
1 paper towel holder
1 long nose pliers

Procedure

We are going to need a lot of wire for the rest of the activities, so let's take a moment and figure out how to prep some wire.

Open the wire set package and remove the wire loops. It's best to leave the wire loops coiled and tied off until you need them.

Once you start using a wire, it's easy for it to get tangled. To avoid this, keep the loop on a paper towel holder, laboratory ring stand, or similar object.

The wire has a plastic insulating coating. This keeps the electrons in the wire from flowing where you don't want them to. However, the ends of the wire must be bare metal, so you need to "strip" away the plastic insulation. There are several ways to do this. We will use the long nose pliers to both cut and strip the wires.

The pliers have a small section with scissor-like blades. Use this section to cut a 30- to 40-cm piece of wire. It may require a bit of twisting and pulling while you hold the blades clamped around the wire.

Use the same section of the pliers to strip the wire. Place one end of the wire between the blades of the long nose pliers, with several centimeters sticking out the other side. Lightly close the blades together around the wire, then gently pull the long end of the wire. If all goes well, the last few centimeters of plastic insulation should slide off. If you accidently cut off the end, just try again with the same wire, which is now just slightly shorter.

Repeat with the other end of the wire. Then repeat the entire process with several more 30- to 40-cm pieces of wire. You're going to need at least four sections of wire with the ends stripped.

Handout 6 ▸p.1

It's Hot, Please Close the Fan

Using a flathead screwdriver we'd hammered out of a bicycle spoke, I removed the screws from the International radio cover and tossed it aside. I removed the cassette deck, and behind it, I found the radio motor. It was half as long as my index finger and as round as an AA battery. A piece of metal stuck out from the top like a stem, attached to a small copper pulley wheel that hoisted a thin rubber belt.

I carefully extracted the motor.

—William Kamkwamba

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 organizer case for storing batteries
1 personal mini fan
2 AA batteries
1 precision screwdriver set
1 package of binder clips
4 stripped wires from the **Handout 5** activity

Procedure

1. First, let's test the personal mini fan to make sure it works. Open the battery case. Place two AA batteries in the battery holder. The plus (+) side of each battery should align with the + symbol on the case. Likewise, the minus (–) signs should also match up; the minus side of the battery holder has a small spring on it. Then move the switch to the ON position. The fan should start spinning rapidly.

2. Now take apart the entire apparatus and remove the motor. First, remove the fan itself. It should come off with a bit of gentle tugging. The rest of the case is held on by a small screw. Unscrew it with a screwdriver from the precision screwdriver set.

3. Remove the motor wire from the metal tab on the plus side of the battery holder. It is only lightly soldered onto the metal tab, and it should come off with a bit of gentle tugging. Then remove the other end from the motor. You can discard or recycle this bit of wire. Twist and bend up the metal tab on the minus side of the battery holder, where the switch used to be. The tab should stick out of the battery holder, so you can attach wires to it easily.

Handout 6 ▸P.2

It's Hot, Please Close the Fan

4. The tab on the plus side of the battery holder is very small. Extend it by attaching a small clip from the binder clips package.

5. Using a couple of pieces of the wire you cut and stripped earlier, figure out how to connect the fan motor so that it will run. Leave the fan attachment off, so that the entire thing doesn't flap all over the place once it's running.

6. Place two batteries in the battery holder to test it. It will probably take some trial and error. Make sure the wires are connected metal-to-metal. You may want to look at another fan that has not yet been taken apart for hints.

For any electrical device to work properly, there must be a **closed circuit**. Put another way, there must be a complete, unbroken loop of metal or other conductive material for charged particles to flow through. If there's a gap anywhere, it won't work. A circuit with one or more gaps is called an **open circuit**. Once you get the motor running, see if you can trace the path of this closed circuit.

By the way, you might be wondering if the positive and negative signs have anything to do with positive and negative charges. They do. If there's a closed circuit, then electrons, which are negatively charged, flow out of the negative side of the battery. They then flow around the circuit, and back into the positive side of the battery. Then the electrons flow through the battery and back out the other side. (Sometimes instead of electrons flowing through the battery, positively charged molecules flow the other way. But this amounts to the same overall effect.)

Does a circuit use up electrons? No. This is a common misunderstanding. A used-up battery has just as many electrons, and just as much charge, as a new, fully "charged" battery. In a circuit, the electrons just flow around and around, never leaving the circuit. The amount of electrons or other charged particles flowing around the circuit every second is called the **current**.

So what gets used up? The chemical energy in the battery gets used up. Even then, the energy doesn't stop existing. It just gets turned into other forms, such as thermal energy.

Handout 7 ▸ p. 1

Pumps and Tanks

"How do I know which head is positive or negative"? Geoffrey asked.

"If you connect the wires and you hear music, you got the right one."

"Whatever you say. Here it goes."

—William Kamkwamba and his cousin Geoffrey

Materials

1 pair of safety goggles for each person
1 motor from the **Handout 6** activity
1 AA battery
1 roll of PVC electrical tape
1 9-volt battery
1 D cell battery
4 stripped wires from the **Handout 5** activity

Procedure

1. We won't be using the battery holder any longer. You'll just need the motor from the personal mini fan.

Make a prediction to answer this question: Will the motor run with just one AA battery instead of two?

- ☐ **A.** No, one battery is not enough.
- ☐ **B.** Yes, but it will run more slowly than with two batteries.
- ☐ **C.** Yes, it will run at the same speed as with two batteries.
- ☐ **D.** Yes, and it will run even faster than with two batteries.

Now explain why you made this prediction.

Handout 7 ▸ P. 2

Pumps and Tanks

(Make a prediction, and have a reason for it, before you try the experiment! This is how science goes. It's exciting when your prediction is right, of course. But it's even more exciting when your prediction is ***wrong***. That tells you that something funny is going on. It reminds you that the universe is more interesting than you thought at first. That's how you learn science. The most boring way, of course, is to skip ahead and try to hunt for the answer. Or hope someone else has figured it out first, and get it from him or her. As the American physicist Paul Hewitt would say, that's like hoping to get stronger by watching another person do pushups.)

2. Now test your prediction. Remember, you're trying to make a complete circuit. Try a few different methods before you settle on an answer. It may help to use some bits of PVC electrical tape to hold the wires where you want them to stay. Briefly record what you tried and what happened.

3. The motor spindle rotates too quickly to count the spins. But listen carefully. When the motor is running, how can you tell if the motor is running faster or slower?

4. What will happen if you hook up the fan circuit backwards? That is, switch the minus side of the fan to the plus side of the battery holder, and the plus side of the fan to the minus side of the battery holder.

- ☐ **A.** The fan won't run.
- ☐ **B.** The fan will run backward.
- ☐ **C.** The fan will run forward.

Now explain your reasons for your prediction.

5. Test your prediction. Briefly record what you tried and what happened.

6. Make a prediction: Will the motor run with just one 9-volt battery?

- ☐ **A.** No, it's only designed for AA batteries.
- ☐ **B.** Yes, but it will run more slowly than with a single AA battery.
- ☐ **C.** Yes, it will run at the same speed as with a single AA battery.
- ☐ **D.** Yes, and it will run even faster than with a single AA battery.

Now explain your reasons for your prediction.

Handout 7 ▸ P. 3

Pumps and Tanks

7. Again, test your prediction. Unlike with the AA battery, the positive and negative terminals of the 9-volt battery are on the same end. Try to avoid letting a single wire touch both the positive and negative terminals of the battery. This will cause a **short circuit**, which will heat up and ruin your battery. Briefly record what you tried and what happened.

8. Make a prediction: Will the motor run with one D cell battery?

- ☐ **A.** No, it's only designed for AA batteries.
- ☐ **B.** Yes, but it will run more slowly than with a single AA battery.
- ☐ **C.** Yes, it will run at the same speed as with a single AA battery.
- ☐ **D.** Yes, and it will run even faster than with a single AA battery.

Now explain your reasons for your prediction.

9. Test your prediction. Briefly record what you tried and what happened.

Look at the labeling on the AAA, AA, C, and D cell batteries. Notice that they're all labeled "1.5 V." This stands for 1.5 volts. Voltage (also called electric potential) is measured in volts. Voltage is the amount of "oomph" the battery has. It tells how much energy it gives to each charged particle that passes through it per unit charge. In fact, the real name for the "oomph" of a battery is the electromotive force or emf. A battery is sort of like a water pump. The emf tells you how hard it pumps.

AAA, AA, C, and D cells all have the same emf, even though they are different sizes. The size tells you more about how much energy a battery can **store**.

So besides acting like a water pump, a battery is also like a water tank. The bigger the battery, the more it can hold in its "tank." As you use a battery, the amount of energy it has decreases, but the emf stays roughly constant. However, when the battery is close to being used up, its emf does drop by quite a bit. You've probably experienced this if you've used a cordless electric drill, electric toothbrush, or electric razor for any significant amount of time. Similarly, when you pump the last bits of water out of a tank, it may come out only in fits and spirts.

The 9-volt battery, as its name implies, has six times the emf of a 1.5-volt battery.

Handout 8 ▸p.1

Series and Parallel

Materials

1 pair of safety goggles for each person
2 motors from the **Handout 6** activity
6 AA batteries
1 roll of PVC electrical tape
1 9 V battery
1 D cell battery
4 stripped wires from the **Handout 5** activity
Computer access or projector to view video

Procedure

1. When you first started the fan, the two AA batteries were connected in **series**. This means that the batteries were essentially lined up, with the positive end of one connected to the negative end of the other, and with the other ends connected to either side of the motor.

   Try to connect two AA batteries in series to the motor, but this time without the battery holder.

2. Make a prediction: What will happen if you run the motor with six AA batteries in series?
   - ☐ **A.** The motor will run slower than with two AA batteries.
   - ☐ **B.** The motor will run at the same speed as with two AA batteries.
   - ☐ **C.** The motor will run faster than with two AA batteries, but slower than with a single 9-volt battery.
   - ☐ **D.** The motor will run at the same speed as with a single 9-volt battery.
   - ☐ **E.** The motor will run faster than with a single 9-volt battery.

   Now explain your reasons for your prediction.

3. Test your prediction. Briefly record what you tried and what happened.

Handout 8 ▸P.2

Series and Parallel

4. Each battery "pumps" with 1.5 volts. Each battery in series makes its contribution, and pumps more energy into the moving charged particles. Of course, there is a limit to this. Once a certain number of charges is flowing by every second, the battery gets worse at pumping. You end up losing a lot of energy and just heating up the batteries. So it's very inefficient to try to make a "super battery" by connecting hundreds of batteries in series. It's also rather dangerous. Watch this video:

Fun with a few 9V batteries. (244 of them)
https://www.youtube.com/watch?v=8hwLHdBTQ7s

5. If you can put batteries in series, why not motors in series too? If you connect a single AA battery to two motors in series, how will the motors run? Make your prediction:

- ☐ **A.** The two motors won't run at all.
- ☐ **B.** They will both run, but the motor closest to the positive side of the battery will run faster.
- ☐ **C.** They will both run, but the motor closest to the negative side of the battery will run faster.
- ☐ **D.** They will both run at the same speed as each other, but slower than with one motor and one AA battery.
- ☐ **E.** They will both run at the same speed as with one motor and one AA battery.

Now explain your reasons for your prediction.

6. Test your prediction. Briefly record what you tried and what happened.

7. If a battery is like a pump that adds energy to the flowing charged particles in the wire, then a motor is like an "anti-pump". It removes energy from the particles by spinning the fan's spindle.

But a battery is also like a tank that stores energy. So where is the "anti-tank"? The room around you. Energy is carried away from the tank in the form of vibrating air (sound) and the vibrations of the table underneath. There's also a little friction between the parts inside the motor, which heats up the motor slightly. A small amount of energy also goes into heating up the wire and the battery.

Another way to connect multiple batteries is in **parallel**. One way to make batteries in parallel is to make them parallel in the math sense: put them next to each other and facing the same way. Once they're lined up, you can tape them together. Then tape one wire so that one of its stripped ends lies across ***all*** the negative terminals. (See image at right.)

Handout 8 ▸p.3

Series and Parallel

Tape a different wire the same way, but instead across ***all*** the positive terminals. (Do not use the same wire, as that will result in a short circuit.)

(See image at right.)

8. What will happen when you connect one motor to two AA batteries that are in parallel with each other?

- ☐ **A.** The motor will run slower than with one AA battery.
- ☐ **B.** The motor will run just as fast as with one AA battery.
- ☐ **C.** The motor will run faster than with one AA battery, but slower than with two AA batteries in series.
- ☐ **D.** The motor will run just as fast as with two AA batteries in series.

Now explain your reasons for your prediction.

9. Test your prediction. Briefly record what you tried and what happened.

Having two batteries in parallel is just like having two tanks of water next to each other. The combined emf gives each charged particle in the circuit the same amount of energy as it does with one battery. However, since you have two tanks, there is twice as much energy stored.

10. How fast will the motors run if you make a circuit with two motors in parallel, and one battery? What about two motors in parallel connected to two batteries in parallel? Try it! Briefly record what happened.

11. It's possible to connect two batteries so that they're in "anti-parallel." You just turn one of the batteries in parallel around, so that one battery is positive side up and the other one is negative side up.

Handout 8 ▸p.4

Series and Parallel

What will happen if you connect two batteries in "anti-parallel" to a single motor?

☐ **A.** It makes no difference – the motor will run in the same way it did when the batteries were in parallel.

☐ **B.** The batteries will cancel each other out, and the motor won't run.

☐ **C.** There will be a short circuit, and the batteries will start getting hot.

Now explain your reasons for your prediction.

12. Test your prediction. Briefly record what you tried and what happened.

Handout 9 ▸ p. 1

E&M Epilogue

Materials

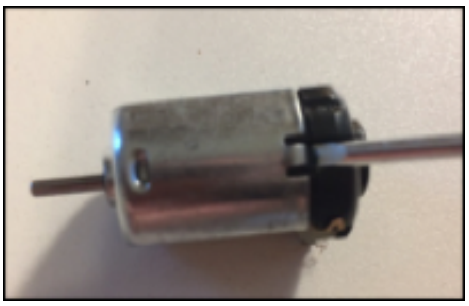
1 motor from the **Handout 6** activity
1 precision screwdriver set

Procedure

Electricity isn't magnetism, and magnetism isn't electricity. But it seems like they ***should*** be related somehow. Are they? Yes, they are. The key to it all is in this little thing.

1. First of all, test it. Is it magnetized? Is the entire thing a magnet? Briefly record what you tried and what happened.

2. OK, let's open it up. There are two little metal tabs on either side of the motor. Bend them up with a screwdriver.



Carefully pull apart the black plastic part and the metal shell. Now comes the fun. Did anyone give William Kamkwamba instructions for his windmill? Of course not. Yes, it helped a whole lot to read about some of the basic principles in *Using Energy* and other books. But in the end, he had to figure out most of it himself.

Handout 9 ▸p.2

E&M Epilogue

Here are some questions to guide you.

- Where's the circuit? What's the path that the electrons follow?
- Can you put it back together and make it run, but without the metal shell?
- Does the circuit pass through any magnetic part?
- What's with all the winding? (You'll see when you open it up.) How long is it?
- If there's a circuit, how does it stay closed while the thing is rotating?
- Where's the magnet? What's it doing there? Is it part of the circuit itself?

When you finally get stumped, look up "DC motor." The DC stands for **direct current**. The other major type of motor—which this one is not—is called an "AC motor". The AC stands for **alternating current**, which is the kind that typical wall outlets provide.

Have fun!

In a simple electric motor, a coil of wire on a shaft is housed inside a larger magnet. When the coil is connected to a battery and becomes magnetized, it creates a kind of fight with the larger magnet. The push and pull between the two magnetic fields causes the shaft to spin. Take, for instance, the fan that we use in hot weather. The blades spin round and round because there's a fight going on inside the fan.

—William Kamkwamba

The Character of William Kamkwamba

Enduring Understandings

- What we learn in school and from books can help us to improve our lives.
- Family relationships can endure through times of great stress.
- One person's talents can benefit an entire community.
- Desperate circumstances can evoke diverse responses, some positive, some negative.

Essential Questions

- What personal characteristics enable William to devise a windmill so beneficial to his community?
- How do individuals' responses to stress and catastrophe affect others?
- Is school learning a right or a privilege?
- How are we affected by and how can we respond to the influences around us (environment, politics, culture, media, etc.)?

Notes to the teacher

As they watch *The Boy Who Harnessed the Wind*, many people find themselves entering a world very different from their own. Malawi is far away on the east side of Africa, and for viewers who live in cities and suburbs, strenuous physical work on a farm is remote. Even for those who make a living on farms or orchards and who know what it means to have products ruined by hail, frost, or insects, starvation is not a likely outcome. On the other hand, young people (and older ones, too) can find many connections with William Kamkwamba and his family and can gain new perspectives from their experiences leading up to the successful construction of the windmill and water pump.

This lesson focuses on William, a young teenage boy with natural mechanical skills and an intense desire to attend school and do well there. As we see him in the movie, William is hard-working, respectful of his parents and other authorities, intelligent, self-confident, persistent, inquisitive, and energetic. On several occasions we also see him as brave and able to find alternative ways to pursue an objective.

In two ways some students may find themselves very different from William. One is his keen desire for schooling and knowledge. The film can lead to the insight that education is a privilege not available to everyone everywhere and that it can improve our lives. The other is the respectful behavior he extends even in circumstances that might evoke a retaliatory outburst from many people. He does not rage at the school headmaster, and he does not rebel at his father's expressions of anger and frustration. In both situations, he benefits more from restraint than he would have from outrage.

In Part 1 of this lesson, students view the film, which takes slightly less than two hours, and respond to a viewer-response guide. They share responses with partners or small groups, participate in large-group discussion, and complete a short writing assignment as an assessment activity.

In Part 2, the class considers the impact of outside forces on William. These include religion, politics, the environment, and the field of knowledge about the generation of energy. In the film, religion is in the background but nonetheless forceful. Christianity is present from the funeral ceremony near the beginning. The traditional religion is embodied by the colorful dancers clearly loved by the people. Islam is also there, hinted at through manner of dress and at the chief's funeral. The two funeral scenes, which frame the film, work well to focus discussion on this topic. To discuss the role of politics, you may want to focus on the political rally during which Chief Wimbe speaks and is then attacked. To discuss the environment, it is useful to juxtapose scenes of torrential rain and flooding with those of scorched and barren earth, followed by the windmill providing irrigation water near the end. Finally, the movie shows William's progress from the ability to work with batteries to his interest in generating light and onward to the complexities involved in using a windmill as a source for the power to pump water out of a well.

In Part 3 students switch their attention to the real William, now a college graduate and consultant who travels all over the world. For this you will use a TED presentation, and students will use other websites to gather information. Students then respond to the quote, "I try, and I made it."

Common Core State Standards addressed by this lesson

CCSS.ELA-Literacy.CCRA.R.1
Read closely to determine what the text says explicitly and to make inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

CCSS.ELA-Literacy.CCRA.R.2
Analyze how and why individuals, events, or ideas develop and interact over the course of a text.

CCSS.ELA-Literacy.CCRA.W2
Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through effective selection, organization, and analysis of content.

CCSS.ELA-Literacy.CCRA.W.4
Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

CCSS.ELA-Literacy.CCRA.W.8
Gather relevant information from multiple print and digital sources; assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.

CCSS.ELA-Literacy.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.CCRA.SL.4
Present information, findings, and supporting evidence such that the listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

Duration of lesson

5–6 class days, including time to view the film

Assessments

Responses to **Handout 1**, the viewer guide

A short writing in response to the film

Participation in group presentation

A short analytical writing

Participation in class discussion

Culminating essay

Materials

The film *The Boy Who Harnessed the Wind*

Presentation devices with internet access

Internet and word processing access

Copies of **Handouts 1–4** for students' use

Short video "How I Harnessed the Wind" at https://www.ted.com/talks/william_kamkwamba_how_i_harnessed_the_wind.

Procedure

Part 1: Watching the Movie and Responding to It

1. Explain that the class will be focusing on the main character in *The Boy Who Harnessed the Wind*. If this is students' first viewing of the film, provide introductory information. The movie takes place in Malawi, a country in Africa, and centers on a family whose source of income is agriculture. Assure students that, although the film is subtitled, they are likely to find interactions relatively easy to follow.

2. Distribute **Handout 1** for students' use as a viewer-response journal and ask them to complete it as they watch the film. The handout suggests two places to pause for students to record ideas. You may want to select additional moments.

3. After students view the film and complete **Handout 1,** allow a little time for partners or small groups to review and discuss responses to the questions and to make sure their own handouts are complete. (Diverse responses are fine and helpful to discussion.) Then collect the handouts for use in assessment.

4. Explain that the movie is not fiction; it is based on real events and people. Ask students to think about the extent to which they felt engaged in events depicted in the film. Did they find themselves identifying with any of the characters? Why?

5. Conduct a whole-class discussion based on the following questions.

   A. How would you describe William's relationship with his family? (This is a loving family, and William is respectful of his parents. He is expected to help with chores and does so willingly. The family relationships become strained because of the failure of the crops.)
   B. Several times the movie shows William foraging in the local junkyard. Why? (To him discarded items can be seen as tools to solve problems. Faced with difficulties, William's characteristic response is to seek for and create solutions.)
   C. Do you think the headmaster at school was fair to William and the other students who were behind in tuition payments? (For William, universal free public education does not extend past elementary school; his high school is tuition-based. Do young people have a right to attend school? Did the headmaster have a choice?)
   D. What moment in the movie strikes you as most impactful? Why? (Possibilities abound, including the political rally and assault on Chief Wimbe; Trywell's explosive response to William in the barren field; William's response to the death of his dog; the windmill succeeding in pumping water out of the well.)
   E. Point out that **Handout 1** asked students to record words and phrases that describe William. Tell the class that each person will be asked to name one trait that is important to describe his character. They will also need back-up ideas to avoid redundancy. As students identify characteristics, record them on the board. (Examples: intelligent; mechanically gifted; persistent; respectful; inquisitive; friendly; loyal; helpful; brave.)

6. Ask students to write paragraphs in which they respond to the following prompt: The thing that strikes me the most about William Kamkwamba is his _____ when _____. Collect writings for use as assessment tools.

Part 2: Outside Influences on William

1. Point out that William's character development is affected by forces outside of himself and that, in fact, this is true of everyone in real life. Ask students to brainstorm the ways outside forces intrude to affect their own thoughts and actions. (Examples: A tornado can demolish a home and force a family to start all over again with basic necessities such as food, water, and shelter. Political decisions can make neighborhoods better places to live or cause them to decline. New developments in technology render some items obsolete and cause people to develop new skills.)

2. Divide the class into small groups and assign each group one of the following topics: religion; politics; weather; scientific knowledge. Tell students that their job is to analyze the role of the topic in the film and the ways it affects William and the other characters. They will then present their findings to the class as a whole. (Note: Although students can do this from their memories of the movie, it is much more effective if they can access it and review sections pertinent to the assigned topics.)

3. Distribute **Handout 2** for groups to use as a guide in researching their topics and creating their presentations. If necessary, assist students who have trouble getting started or knowing how to proceed. Allow sufficient time for groups to access information and organize content.

4. Distribute **HANDOUT 3** for note-taking purposes during the presentations.

Suggested Responses:

Religion is an influence but not an intrusive factor. Perhaps the most important scenes are the two funerals and Trywell's prayers with the family. The movie reflects Malawi's dominant religion, Christianity, as well as its significant Muslim population. It also shows the influence of traditional pre-Christian beliefs and practices sometimes referred to as animism. These belief systems seem to coexist in harmony. For example, at Chief Wimbe's funeral, William and Gilbert stand side-by-side and appreciatively look at the colorful traditional dancers. Perhaps the greatest influence on William would be a spirit of tolerance and appreciation toward religious differences, a sense that those differences are complementary rather than a cause for dissension or hostility.

Politics is a significant factor. We see it early in the rally in the village. Trywell sets off toward a demonstration about the farmers' needs. Inadequate government assistance provokes mob violence. Most important is the scene in which officials visit Wimbe with much panoply; when the chief speaks his mind, he is hustled off stage and severely beaten. William and his friend Gilbert clearly know that the chief is in serious danger and are among the first to arrive to intervene, leading to the quick departure of the political figures. Perhaps the result for William would be the idea that government cannot be trusted and that people can and must look out for themselves.

Malawi's environment can be harsh, with torrential rains and flooding followed by long arid periods. Thus the vast majority of Malawians are in constant danger of inadequate nutrition. Deforestation is a complicating issue. The crops are always at risk. Many scenes in the movie can be used, among them Trywell's desperate efforts to divert flood waters, the attempt to glean at least some grain from the devastated crops, the labor on the fields during drought, and the final scene of the windmill's power to provide electricity to pump water for irrigation. The environment prompts William to seek solutions, which he finds through science and technology.

As he begins secondary school, which is not required in Malawi, William is a neophyte in scientific knowledge, although he is significantly skilled with mechanical things. He is able to repair radios, an important source of entertainment to the villagers. His need for a light source to enable him to study at night leads him to Mr. Kachigunda's bicycle and the discovery that motion can generate power. When William cannot attend school, he uses the library and discovers books about electricity's causes and uses. This leads ultimately to the success of the windmill. William values knowledge, particularly its practical applications.

5. Ask students to complete short writings in which they reflect on how the film's presentation of one of the four influencing factors can relate to their own lives and attitudes today. Collect the writings for assessment. You may want to create a montage of interesting excerpts from the writings and distribute copies to the class for use as a basis for discussion.

Part 3: The Real William Kamkwamba

1. Have students review the short clip near the end of the movie in which William and his father talk about the future. Ask partners to collaborate to answer the following question: What do you think happened to William after the events depicted in the film? (Note: If you let the film run clear through the credits at the end, students will have some clear information on the subject.)

2. Ask students who think William stayed in Wimbe to help his family on the farm to move to one side of the room. Ask those who think he continued on with further education to move to another. Ask those who foresee some other outcome to stand where they are. Then have two or three members of each group explain their thinking.

3. Point out that *The Boy Who Harnessed the Wind* presents some important experiences in William's life, but it does not present William himself. The roles are played by actors, and some elements are condensed and altered to suit the film medium and the director's goals. The film's time setting is early in the first decade of this century, so William is now a grown man, and we can verify which group came closest to what has really happened.

4. Have the class view the short video (about 5 minutes) "How I Harnessed the Wind" at https://www.ted.com/talks/william_kamkwamba_how_i_harnessed_the_wind.

5. Explain that William has also given other presentations and participated in interviews. Ask students to use the Internet to access several of these and to view them carefully. (Note: Several can be found on YouTube, as well as the TED site.) Students can also look for additional sites that provide information about William; the movie has evoked considerable media interest in him.

6. Distribute **Handout 4** and ask students to use it to record information. Tell them that they will be able to add to it later during class discussion.

7. Lead a discussion based on the handout questions.

Suggested Responses

- **A.** William was one of seven children and was the only boy. The movie simplifies the family, but in real life drought and famine must have been even more terrifying.
- **B.** He did not want to be caught in the cycles of poverty that often afflict subsistence farmers. Education was a welcome way out of a no-win situation,
- **C.** He describes a fascination with how and why things work. Why, for example, does turning a key make a car engine start?
- **D.** At first, he returned to school in Malawi, but eventually he completed high school in South Africa.
- **E.** The successful creation of the windmill attracted media attention, and in 2007 William was invited to participate in a TED conference in Tanzania. Clearly his life was changing radically from that of the young boy he used to be.
- **F.** He had the opportunity to attend Dartmouth, a prestigious college in New Hampshire in the United States. He graduated in 2014 with a bachelor's degree in environmental studies.
- **G.** He is based in the United States, but travels all over the world as a consultant and speaker.
- **H.** Write the following quote from William on the board: "I try, and I made it." Assign students to write essays

in which they respond to it, including the following: references to the movie; references to the real William; and reflections on how the comment relates to their own lives. You may want to establish a time for peer conferences as well as a due date.

Extension Activity

Invite students to complete projects or essays in which they examine the role and development of another significant character in the film: William's father or mother; Annie; Gilbert; Chief Wimbe; or another figure that they found intriguing.

Handout 1 ▸ P. 1

Viewer Response Journal

A. During the first half-hour of the film, the viewer becomes acquainted with William Kamkwamba and the circumstances of his life. Stop viewing after the scene in which William and some of his schoolmates find that they cannot attend classes because of incomplete tuition payments and the following scene showing heavy rains and consequent flooding of the fields. (34:04) Use the following questions to consider your insights and responses:

1. In what ways does William's life seem like/unlike yours and the lives of your friends?

2. What forces in the world are likely to affect him and his family, friends, and neighbors, whether or not they fully understand those forces?

3. What seems to be William's attitude toward school? Is it the same as or different from yours? Explain.

4. Based on these opening moments in the movie, what character and personality traits have you observed in William? List at least five.

Handout 1 ▸ P. 2

Viewer Response Journal

B. Continue viewing up to and including the meeting of William's family with the school headmaster (1:18:43). As you view, focus primarily on William's actions and reactions. Then consider the following questions.

5. A number of times in the movie we see the area used to dump what is viewed as useless trash. How does William view the area? What does this show about him?

6. Why are the people suffering a devastating food shortage? What reactions do you see? How does William respond?

7. What tensions are brewing in William's family? How do they seem to affect him?

8. How do you react to the decisions of the school principal? How does William respond? What does this show about him?

Handout 1 ▸ P. 3

Viewer Response Journal

C. View the rest of the movie and consider the following points.

9. William's father's great anger and frustration lead him to lash out as his son. How does William react? Would you have responded the same way? Why or why not?

10. The film depicts many losses. How do the characters, including William, react to them?

11. The creation of the windmill and resulting ability to irrigate the land are a triumph. What does the windmill reveal about William? In what ways does it operate as a symbol?

12. Now that you have seen the entire film, write a sentence in which you identify what you see as three of William's most important personal characteristics.

Handout 2

Focus Group: Analyzing a Topic and Creating a Presentation

Use the following steps to guide your work and check off when each has been completed.

Group Members:_____

_____

1. Make preliminary observations about what you remember about your topic in the development of the movie. How impactful did it seem to you at the time?	
2. Define your topic. What does it include and not include? How important is it?	
3. Identify moments in the film when your topic is evident. Closely review those moments and focus on details. Then decide how you can incorporate them as visual elements in your presentation.	
4. Pinpoint related topics that need additional clarification and conduct relevant research.	
5. Plan the content of your presentation. Create a guiding thesis statement that summarizes the ways your topic impacts William. Explain how and why it has those impacts. What effect would omitting your topic have on the movie as a whole?	
6. Decide on the best format for your group's presentation. Do you want to create a multi-media presentation or a video, or would you prefer to perform live? Would a debate or panel discussion work well? How about using an interview session or a dramatization?	
7. Assign responsibilities so that each group member can make a significant contribution to the final result. Set a time to gather everything together and for rehearsal. Make sure your presentation clearly shows the role of each group member, just as a movie screen identifies actors, director(s), and crew.	
8. Make the official presentation to the class.	

Handout 3

Outside Influences on William Kamkwamba

Use the chart to take notes on each topic, including relevant scenes and analytical observations.

Topic	Film scenes	Analysis
Religion		
Politics		
Environment		
Scientific Knowledge		

Handout 4 ▸ P. 1

The Real William Kamkwamba

Research to find the answers to the following questions

1. How did the real family with whom he grew up differ from the one presented in the movie?

2. How does William explain the intense desire for an education that he felt even as a young boy?

3. What kinds of questions seem to have fascinated him?

4. In the movie, his education stops when he has barely begun his first semester of high school. How did he eventually get a high school diploma?

Handout 4 ▸ P. 2

The Real William Kamkwamba

5. How and why did his life change in 2007?

6. What kind of post-secondary school education did he receive?

7. What is his life like now?

Film as Literature: Understanding Tone

Enduring Understandings

- Tone in literature refers to the author's attitude toward the subject. Films also have tone, established by the filmmakers.
- While the writer uses word choice to establish tone, the director of a film can use many cinematic techniques.

Essential Questions

- What are some of the cinematic techniques that a director can use to establish the tone of a film or of scenes within the film?
- How does the visual/auditory construction of a scene affect the overall tone and narrative of the film?

Notes to the Teacher

The goal of this lesson is not only to teach about the filmmaker's techniques used in *The Boy Who Harnessed the Wind*, but also to help students become active, critical viewers of any film. Students know, in an instinctive way, whether or not a film is well-made. They often lack only the language and tools to make discriminating choices. Adults might be baffled as to some of their choices (grotesque horror movies, tacky dance films, screwball comedies), but students can be as analytical about those genres as any other if they use simple tools that they have learned in class, including how to analyze tone. **Tone** refers to the filmmaker's attitude toward his or her subject, which in a well-made film is conveyed to the audience by filmmaking elements such as lighting, camera angles, movement, cuts, and dialogue.

The Boy Who Harnessed the Wind is a wonderful exploration into how the tone of a scene in the film adds to the effectiveness of the story. The same script in another director's hands could deliver a completely different film, for better or worse. In this film, the screen writer and director are one and the same. With this in mind, it would be useful for students to explore whether having control of both the story and the interpretation is a blessing or a curse.

Some additional resources you may wish to consult for this lesson are:

Use of lighting, exposure, and art direction
https://www.youtube.com/watch?v=Tkbto1oLAnE

How to Write a Great Scene by Michael Hauge & Mark W. Travis
https://www.youtube.com/watch?v=LEiZjXO6Cz4

Common Core Standards Addressed by this Lesson

CCSS.ELA-Literacy.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-Literacy.CCRA.SL.2
Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

CCSS.ELA-Literacy.CCRA.SL.4
Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

Duration of Lesson

Three to five 50-minute class periods

Assessment

Quiz on film terms (optional)

Completion of scene analysis sheet

Short essay

Presentation of clip and analysis

Materials

Appropriate AV equipment to watch the film

Presentation devices with internet access

Computer access

Copies of the Journeys in Film glossary at
https://journeysinfilm.org/product/glossary-of-film-terms/

Copies of **Handout 1**

Film as Literature: Understanding Tone

Procedure

Part 1: Exploring the Meaning of Tone

1. Begin the class with a brief review of a work of literature your students have studied recently. Point out that the author used many techniques to tell the story and to create an effect on the reader. List some of these techniques on the board, such as syntax, diction, imagery, and figurative language.

2. Now add the word "tone" to the list and write the definition for students: "Tone is the author's attitude toward his subject or theme." Discuss how tone is conveyed through word choices, the way words are arranged, and images drawn by the author.

3. Ask students to brainstorm a list of possible tones they might take in writing about their families (for example, loving, respectful, fearful, angry, sad, enthusiastic). After students have volunteered some examples, point out that there are as many tones as there are emotions. Project the list of tone words that can be found at https://writerswrite.co.za/155-words-to-describe-an-authors-tone/ and review it briefly with students. Ask them to save this URL so that they can refer to it in the future.

4. Remind students that an author creates the tone of his or her work by word choices, word arrangements, and figures of speech that are used. Ask what techniques a filmmaker might use to create tone and encourage discussion of student suggestions.

Part 2: Tone in Film

1. Take a quick poll of students about their favorite movies. Have them attempt to explain why they like these films. Then tell them that, after this assignment, they will be able to watch their favorite film again and explain much more clearly their reasons for liking it. That is, after all, how all of the world's great directors learned—closely watching the same films over and over again.

2. Distribute the copies of the film glossary and have students highlight the terms you will be using in this lesson. Depending on the students' familiarity with these terms, you may wish to review the most important ones for this lesson or perhaps even give a quick quiz on them. Here are some terms which should definitely be included in your discussion:

   Long shot
   Key lighting
   Montage
   Camera angle
   Camera movements
   Close up
   Focus
   Reverse angle
   Shot
   Handheld shot
   Scene

3. Tell students that they are going to focus now on camera movements, watching a short video explanation of how camera movements affect tone. List the following terms on the board: pan, tilt, zoom, dolly, reverse dolly zoom, pedestal shot, crane/boom, steady cam, handheld, rack focus; have the students copy them into their notebooks, leaving space to take notes. Show the video at https://www.youtube.com/watch?v=Tkbto1oLAnE a little at a time, stopping after each explanation of a term and asking the students to explain (a) what the term means and (b) how each of these camera movements might affect the tone of a scene.

4. Point out that other elements of filmmaking—lighting, music, pacing and more—can also affect tone. The more students know about film techniques, the more they can analyze and appreciate the quality of a film.

Part 3: Group Scene Analysis

1. Distribute **Handout 1: Scene Selection Sheet** and review the directions for students.

2. Replay the clips indicated on the handout. After each clip, allow time for students to take notes on their observations. Offer to replay the clip if that would be helpful. After students have written down their notes, discuss each clip with them. Then continue with the next clip until they have viewed all five scenes and analyzed them.

Some possible ideas for discussion:

Scene 1: Death of a father (1:32 – 2:57)
The tone of the entire film is set in the opening scene. A brutal blaze of light is omnipresent and serves as a warning of harsh weather on the way. A high, tilt-down shot from the sun reveals the unfruitful setting as well as a close-up of a basket with corn to indicate the importance of the crop for survival. Yet, the arrival of the Gule Wamkulu, framed in wide and long shot, suggests an equally ever-present spiritual guidance. In introducing this presence, the camera does not pan or track; it simply lets the players pass, suggesting that they are a calming fragment of the heartless countryside. When the Gule Wamkulu arrive at the funeral of John, it is clear that this film will show a contrast between faith in ritual and the realities of the world itself. The tone of this film, it is revealed, is a combination of acceptance and hopefulness.

Scene 2: William washing (8:37 – 9:25)
This scene is about establishing the domestic lifestyle that will soon be interrupted by the coming drought. The overhead shot of the bucket of water shows both that water is essential, although not readily obtainable by faucet, and is still available. As William washes, quick shots (dipping water, scrubbing hair, etc.), show the viewer that, by Malawian standards, this is a happy, healthy home, and the action is rather routine. One might even go as far as calling this tone bucolic or pastoral. By doing this, the gravity of the drought will be all the more fierce.

Film as Literature: Understanding Tone

Scene 3: The light on the bike (29:00 – 30:15)

As the camera moves along with William's actions, the tone of desperation is enhanced. Up, down, side-to-side, the camera follows as William is in the act of stealing. This camera movement continues as he discovers the wiring of the bike and an act of theft becomes a moment of enlightenment. The tone of the scene changes from anxiety to one of wonderment and intrigue. What starts out as a moment of stress becomes a moment of hope. The final static shot of William's face is a perfect way to punctuate the otherwise dynamic scene.

Scene 4: One meal a day (1:09:02 – 1:10:11)

The problem, of course, is clear. People are dying and this family needs to make a plan in order to survive. This is enhanced in a cinematic way by the complete lack of camera trickery. The scene is simply a series of fixed shots of distraught faces coupled with sparse, but all-important dialogue. Had the director chosen to move the camera with pans and tilts and even overhead shots, the somber tone of the scene could be lost. Often, a break from camera movement and creative framing will speak more loudly than elaborate cinematography; with more camera movement, this scene's desperate tone might not have been as effective.

Scene 5: Bring it up (1:37:39 – 1:39:40)

Perhaps nowhere in the film are camera placement and movement more crucial than in the first half of this two-part climax. First, the framing of the scene is important and shows the magnitude of the endeavor as large pieces of equipment are juxtaposed against seemingly small villagers. The actual size of the windmill shows the amount of effort that goes into trying to save the village. Additionally, the point of view of both the villagers and William is revealed with high and low camera angles to suggest that William is now in a position of authority and is to be trusted. Next, added to the inserted shots of William's hands with wires (reminiscent of his discovery of the light on the bike) is the elegant 360° camera movement around the windmill, suggesting that he and the wind are somehow one and the same. As the 360° continues, William looks down at the people he is helping and, as he climbs down, he proudly looks up to see the oppressive sun shining through the very device that will save the village. The triumphant tone in this scene is guaranteed with the use of these advanced techniques.

Part 4: Independent Scene Analysis

1. Once you are certain that students understand the previous examples of film analysis, tell them that they are now free to choose a scene from the film to analyze independently. Arrange students in pairs and make sure they have access to the film. Allow sufficient time for students to view the film and identify three scenes they would like to analyze, recording a brief title for each scene and its time stamp, as in the examples on **Handout 1**. Each team should submit their choices.
2. When students have had time to choose their scenes, go through their choices and assign one of the chosen scenes to each pair of students so that each pair is analyzing a different scene.

3. Assign a short essay of one or more paragraphs about their scene, identifying directorial techniques such as camera angles. types of shots, and any other techniques with which they are familiar. The essay should explain how the techniques used demonstrate the filmmaker's tone, i.e., his attitude toward the subject of the scene.

4. When students have finished, allow time in class for students to present their scenes, showing their clip and explaining their analysis of it.

Handout 1 ▸ P. 1

Scene Analysis Sheet

Directions: Watch each of the following scenes carefully. Then answer the questions below. Use any additional space to take notes on other filmmaking techniques you notice and the ways that they affect the tone of the film.

Scene 1: Death of a father (1:32 – 2:57)

Consider why the title frame includes a glaring sun rising. Then the camera shifts from the sun to the overhead shot of the workers. Why? Why does the filmmaker then shoot a close-up of the basket? How does this juxtaposition set the tone for the entire film?

Scene 2: William washing (8:37 – 9:25)

Consider the first shot of the bucket down the well and what it means to the overall story. Then, notice the variety of quick, close-up shots to help the pace of a very short scene. What does this scene tell about William's home life? What is the tone, i.e., the filmmaker's attitude toward his subject?

Handout 1 ▸ P. 2

Scene Analysis Sheet

Scene 3: The light on the bike (29:00 – 30:15)

As with the washing scene, notice the very quick shots and how the camera follows William's hands. How do these shots that follow William add to his new realization? Would the scene work as well with static, unmoving shots?

Scene 4: One meal a day (1:09:02 – 1:10:11)

This intimate scene has only one camera movement. The tilt up from the bag of grain is called an "establishing shot," one that sets the scene. Why did the director choose to film the scene in this way when he had at his disposal all the possible camera movements and placements? How does this signify the important situation that is taking place?

Handout 1 ▸ P. 3

Scene Analysis Sheet

Scene 5: Bring it up (1:37:39 – 1:39:40).

Since this is the first half of the climax, the director uses every trick in his box. How many shots are there and what kind of movement is taking place? How has the director framed each shot? How many camera angles does the director use and what is the effect of these choices?

Helping the Children of Malawi

Enduring Understandings

- While culturally rich, Malawi faces a myriad of issues that affect whether children and families thrive or survive now and in the future.
- There are multiple ways to alleviate these issues, and many organizations are currently working in Malawi to bring about change.
- Students can have an impact on the world around them in both large and small ways.

Essential Questions

- What are the issues faced by the children of Malawi?
- What individuals and organizations are trying to improve the lives of these children? What are they doing? What impacts are they having?
- In what ways can students participate in bringing changes to Malawi that can improve the lives of the young people there?

Notes to the Teacher

The children portrayed in *The Boy Who Harnessed the Wind* range in age from the infant William's mother carries to his sister, a young woman who, unable to attend university as she wishes, instead marries and later has four children. Their lives illustrate many of the problems currently faced by people in Malawi. Among them are poverty, infant mortality, inadequate nutrition, and lack of educational facilities. In this lesson, students research these issues and the ways that organizations (including religious groups, NGOs, and governmental agencies like USAID and the Peace Corps) are working to alleviate problems. An optional student service-learning activity extends and completes the lesson.

Malawi gained its independence in 1964 and founded a democratic government. While there have been challenges to the government as a result of election irregularities, corruption, and its inability to help citizens in crisis during times of national famine and rapidly spreading disease, the government has been generally stable, even if its resources are limited. The events in the movie occur during a major, life-threatening drought in 2001 during which food became scarce and the corruption of the government stopped agencies that could have supplied aid from doing so.

In this lesson, students will be introduced to the problems facing children in Malawi and the ways in which relief organizations are attempting to fix these problems. Students will learn more about one of the problems or one of the potential solutions, be asked to explore and evaluate the best partnership for bringing about change for children, and, optionally, participate in providing relief for one of these problems as partners of one of the organizations they have researched. The lesson is designed to be used after students

have watched *The Boy Who Harnessed the Wind* and been introduced to William Kamkwamba and his family, who provide concrete examples of the issues that impact children and show how those issues can be resolved.

Prior to teaching the lesson, teachers should photocopy handouts; make placards (use regular or heavy sheets of paper folded length-wise); reserve library/computer lab space if required for using Internet-connected devices; and talk with their school librarian or media director about any resources that students may use to complete the handouts and prepare for presentations.

The time required for the optional community service extension will vary widely based on the project selected. Teachers may wish to provide specific options that will best fit the time allowed or to allow students more agency in determining the direction and scope of the project if time is available.

Common Core Standards addressed by this lesson

CCSS.ELA-LITERACY.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-LITERACY.CCRA.SL.4
Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

CCSS.ELA-LITERACY.CCRA.W.8
Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.

CCSS.ELA-LITERACY.CCRA.R.1
Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

Helping the Children of Malawi

Duration of lesson

This is a three-part lesson. The first two parts make up the research and presentation component and require three to four hours of class time. If only three hours are available, work may need to be assigned as homework. The (optional) third part, the planning and implementation of the service project, will add additional time to the lesson, depending on the extent and goals of the project. If there are time limitations, explain those at the beginning of Part 3.

Assessment(s)

Class discussions

Completion of handouts

One-minute presentations

Optional community service project

Materials

- Access to library or devices with Internet connection for research
- Timer
- **Handout 1: Issues Children Face in Malawi**
- **Handout 2: Problem Profile**
- **Handout 3: Organization Profile**
- **Handout 4: Problems and Solution in Malawi Exit Ticket**
- **Handout 5: Supporting Action in Malawi**
- Placards identifying each issue and organization researched

Procedure

Part 1: Problems Facing Malawi and Helpful Organizations

1. After viewing *The Boy Who Harnessed the Wind*, ask students to identify the issues that complicate the lives of William and other children in Malawi throughout the film. Brainstorm a list on the board.

2. Ask if there are other issues that are implied but not directly referenced in the film. Add these issues to the list. If you notice there are issues missing or you wish to expand your list further, ask students to use their devices to research other problems facing Malawi. (Please be aware that this simple search may bring students to websites that list problems like female genital mutilation and sexual exploitation. If this is a concern, the teacher may introduce additional issues without student research.) The brainstormed list should include at least the following:

   - Poverty
   - Food insecurity and malnutrition
   - High infant mortality
   - Lack of clean water
   - Inadequate sanitation
   - High rate of HIV/AIDS infection (including parent-child at birth)
   - Orphans/street children
   - Lack of education for girls
   - Expense of post-primary education
   - Child marriage

3. Define the following categories used by UNICEF's Millennium Development Goals program to categorize issues faced by children in the modern world. (See https://www.eird.org/herramientas/eng/partners/unicef/pub_mdg_en.pdf for definitions that can be adapted to a variety of abilities and levels of specifications.) Explain that these goals are not unique to Malawi, but that they are important for ensuring a better world for all children, including the ones in your class right now, as the goals will help to shape the world they will inherit. Then, ask students to categorize the issues from the list created in steps 1 and 2 into the following categories:

   - Child Survival and Development:
   - Basic Education and Gender Equality
   - HIV/AIDS and Children
   - Child Protection

Handout 1 is a chart designed for students to use for this purpose.

4. Once students have completed the handout, ask them to consider the impact of these issues on the everyday life of children using these questions:

   - How does each of the categories impact the community? The country? The continent of Africa? The world?
   - What long term problems will be created if there are no solutions created for these problems?

5. Ask students if any relief is provided to children in the film. Brainstorm a second list, asking students to consider what other actions and resources would be helpful to solve the problems listed on the board in step 1. A complete list should include at least the following:

   - Electricity
   - Water for irrigation
   - Clean water for drinking and bathing
   - Availability of advanced, affordable education for girls in an environment where they are safe and secure
   - Sufficient nutritious food for normal growth and development
   - Health care for expecting mothers, infants, and children
   - Health education for parents and children
   - Reduced cost or free secondary education
   - Minimum age laws for marriage
   - Minimum age laws for child employment

6. Explain to students that there are organizations that have been created to solve the problems they have identified. The organizations have many different goals and their paths align with at least one and often more than one of the solutions defined in the second list.

Helping the Children of Malawi

7. Ask students to search for organizations that provide relief to the children of Malawi, using Internet-connected devices. Give students ten minutes to find several organizations and make note of the names. Then create a master list on the board. If you choose to skip the research step, you may use the list below. You will need a list of 10 organizations.

- Action Aid Malawi
- Advancing Girls' Education in Africa
- Association of Early Childhood Development in Malawi
- Child Legacy International
- Find Your Feet
- Kids' World Outreach Society
- Save the Children International
- Peace Corps
- USAID
- WaterAid

8. Assign each student a problem or an organization to research. An equal number of problems and organizations should be assigned.

9. Distribute copies of **Handout 2** to the students who are researching problems and copies of **Handout 3** to students researching organizations. Allow sufficient time for students to complete each section of the handout using Internet-connected devices for research.

10. When the research is completed, ask students to consider what they have learned about their problem or organization. Then ask them to prepare a one-minute presentation based on the worksheet. [Note: If students need additional time, the work in steps 8 and 9 can be completed as homework or an additional class day may be devoted to research and presentation preparation.

Part 2: Looking for the Best Match

1. Set up the classroom so that desks are in pairs and arranged with an inner circle and an outer circle facing each other. (If you have a large class, you may need two such arrangements.) Students who researched problems are seated in the inner circle facing out. Students who researched organizations are seated in the outer circle facing in. Give each student the appropriate placard to place on his or her desk.

2. Explain to students that they will have one minute each to explain their problem or organization to the other person in their pair. While their partner is talking, they should be considering whether or not their problem/solution pair creates a match that would provide relief to children in Malawi. Tell them to jot down a few notes quickly for each conversation; they will need them at the end of the exercise.

3. Set a timer for one minute and tell students who were assigned problems to begin their one-minute presentation and say, "Begin." At one minute say, "Switch." and announce that the person who is talking in the pair should stop and the person who researched the organization should begin. At the end of one minute say, "Move." The students in

the outer circle should stand, move over one seat to the left, and sit again. Repeat the Begin-Switch-Move process until each person in the outer circle has presented to each person in the inner circle and vice versa.

4. Ask the students to complete **Handout 4** as their "exit ticket." They should indicate the problem or solution that they researched and note which representatives with whom they spoke were the two most and least likely matches for their research topic. Reviewing this exit ticket will give the teacher an opportunity to ensure that the students understand the ways in which the problems in Malawi can be solved.

5. If you are not completing the optional extension in Part 3, wrap up this study by asking several students to share their observations about what kinds of interventions seem to be providing the most relief to the children of Malawi.

Part 3: How Do YOU Want to Change the World? (Optional Community Service Extension)

1. Divide students who researched problems into four groups, based on the general problem areas from **Handout 1**; seat them in different parts of the room. Ask the students who researched organizations to move to the problem area that their organizations seem to address. (The groups will not necessarily be equal in size.) Ask each group to briefly review the one-minute presentations and discussions from the previous class.

2. Direct each group to complete **Handout 5**. Unless your goal is to create a long-term program, encourage them to consider specific ways in which they can help to alleviate the challenge assigned to their group. What resources will they need? Do they have access to those resources? Students should consider if the resources that they can access are sufficient to complete a service project. Spend time with each group to facilitate discussion as the groups work.

3. When students have completed their preparation, ask each group to present its idea to the class. Discuss whether the plan can be executed with the time and resources that are available. Develop consensus around one plan with an identified need, available resources, a partner organization, and student enthusiasm.

4. At this point, you may wish to continue planning work in class or move it to an outside time. Students should arrange to present their service project plan to student government or administration in order to get approval, if it is required. Once a project is approved, allow students to lead the effort. Teachers are encouraged to be a guide on the side, advising but not coordinating, so that students maintain ownership of the project. Once the project is complete, you may wish to ask students to respond to the following prompt: How can students effectively take action to alleviate problems outside of their own community?

Handout 1

Issues Children Face in Malawi

Directions: Using the list you have brainstormed and discussed, put the issues in the broad categories below. You may put issues in more than one box.

Child Survival and Development	**Basic Education and Gender Equality**
HIV/AIDS and Children	**Child Protection**

Handout 2 ▸ P. 1

Problem Profile

Provide answers that are as specific as you can find.

Name of problem: _____

Background (What has caused this problem?)

What are the impacts of the problem on individuals, on groups, and on the society as a whole?

Handout 2 ▸ P. 2

Problem Profile

What methods have been successfully used to alleviate or combat the problem?

What resources are still needed to alleviate the problem?

Handout 3 ▸ P. 1

Organization Profile

Provide answers that are as specific as you can find.

Name of organization_____

Location: _____

Background (How did this organization come into existence?)

Goal(s) of group

Handout 3 ▸ P. 2

Organization Profile

Available resources

Methods used by group

Handout 4

Problems and Solutions in Malawi: Exit Ticket

Name_____

My research focused on the problem/organization of

_____

The two best matches for my problem/organization would be:

1. _____

because _____

_____

2. _____

because _____

_____

The two least likely matches for my problem/organization would be:

1. _____

because _____

_____

2. _____

because _____

_____

Handout 5 ▸P.1

Problems and Solutions in Malawi

It's now time to create a service project of your own to bring support and relief to the children of Malawi. As you learned in *The Boy Who Harnessed the Wind*, it is possible for children to make a difference in the lives of others.

Based on the problem your group has focused on, what organizations that you have learned about can provide effective partnerships for solving this problem? Discuss the options and choose one organization that you would most like to work with.

What resources are needed by the people in this organization to fulfill their mission?

How can you help to provide access to these resources? Be creative as you consider the answer to this question. Remember that William found creative ways to access the resources he needed when it seemed as if there were none.

Handout 5 ▸ P. 2

Problems and Solutions in Malawi

Do you need to seek permission or a local partnership before you begin? If yes, who will do this?

How will you know that you have successfully completed the project?

What steps will need to be taken to complete the project? Include specific tasks. You may need to continue on a separate sheet.

Now prepare a presentation based on this worksheet to share your proposal with the class.

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